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SOLID WASTE MANAGEMENT IN THE INDUSTRIAL CHEMICAL INDUSTRY

RESEARCH CORP. OF NEW ENGLAND

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This report presents the results of a national study to evaluate the solid waste management practices of the industrial chemical industry, embodied by Standard Industrial Classification (SIC) Number 281. Data and information on solid waste management within the industry were obtained through literature review, a questionnaire mailed to a selected group of industrial chemical plants, and field interviews with chemical plant personnel throughtout the country. Presented in the report are the following information and data for the industrial chemical industry on a national basis: (1) quantity and quality (character) of solid waste generated; (2) universal parameters affecting solid waste generation; (3) current storage, collection, and disposal practices; (4) annual operating expenses; (5) analysis of the future trends in solid waste management within the industry and factors might influence them.

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PREFACE

This report on the solid waste management practices of the industrial chemical industry was prepared by The Research Corporation of New England (TRC) pursuant to Contract No. CPE 69-5, for the solid waste management program of the U.S. Environmental Protection Agency. The statements, findings, conclusions, recommendation, and data in this report are not necessarily those of the Agency nor does mention of commerical products imply endorsement by the U.S. Government.

The study was carried out by the Engineering Division of TRC, John E. Yocom, Director. The Program Manager was Peter W. Kalika, and the Project Engineer was J. Kirby Holcombe. Harold Jacobs, Wilmington, Delaware, served as chemical waste consultant. Other participants for TRC were Peter N. Formica, Associate Project Engineer; Scott G. Shanks, Senior Research Scientist; and Charles R. Case, Programmer. Rodney L. Cummins, and George L. Huffman, served as Project Officer for Federal solid waste management programs.

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SOLID WASTE MANAGEMENT
IN THE INDUSTRIAL CHEMICAL INDUSTRY

SECTION ONE: SUMMARY AND CONCLUSIONS

With the passage in October 1965 of the Solid Waste Disposal Act, the Federal Government accepted the responsibility to assist in the improvement of solid waste management practices on a national basis. Upon assuming this responsibility, the Federal solid waste management program was confronted with a lack of comprehensive information with which to define solid waste problems of municipalities and industries in specific terms. A series of industrial studies was instituted by the program in a number of areas, including the packaging industry, the plastics industry, the drug industry, and others, to define industrial solid waste management practices. As one of the series, this study is directed entirely at the industrial chemical industry. The scope of the industrial chemical industry was defined as Bureau of the Census Standard Industrial Classification (SIC) No. 281, and includes all plants producing industrial organic and inorganic chemicals in commercial quantities.

The objective of the study was to evaluate the solid waste management practices of the industrial chemical industry. Information and data were collected for the following items on a national basis: (1) total number of industrial plants, employment, value added by manufacture, and quantities and types of products produced; (2) past development and production patterns within the industry, with an indication of present trends, new technology and future development; (3) flow diagrams for the basic production processes, showing points of solid waste generation; (4) location of industries with identification of production centers in the country; (5) the quantity (weight) and quality (character) of solid waste generated; (6) universal parameters that affect solid waste generation; (7) current storage, collection, treatment, and disposal of solid waste for the industry; (8) analysis of the future trends of solid waste management within the industry and factors which might influence them.

In 1967, the industrial chemical industry consisted of 2,030 plants, and employed 252,000 people. Its value of shipments in 1967 was $14,100 million. The economic importance of this industry to the Nation is emphasized by the fact that it contributes one-third of both value of shipments and value added by manufacture to the chemical and allied products industry, which in turn represents nine percent of value added for all manufacturing industry.

Growth in value added by manufacture for the industry was 83 percent during the 1958-to-1967 period. This figure was not as large as the chemicals and allied products major group (90 percent), and only slight greater than all manufacturing industry (80 percent). Growth of different chemicals has been varied within the industry, however, with some classes of chemicals growing at rates greater than 100 percent over the same period. Recently, growth has been more rapid and value of shipments is predicted to approach $17 billion in 1970.

The middle-Atlantic and north-central regions of the country are the areas of greatest industrial chemical manufacturing activity, on the basis of value added by manufacture. An analysis by state revealed that Texas and New Jersey have the greatest concentration of industrial chemical manufacture, containing over 21 percent of the chemical manufacturing plants in the United States. This figure represents 30 percent of the value added by manufacture of the industry.

Solid waste from industrial chemical plants was categorized as process wastes which are those generated directly from chemical processes and non-process wastes. An average of 690 tons per year per plant of non-process waste was reported by those plants responding to the mail questionnaire, as shown on Table 1. The average process waste quantities were found to be considerably greater, at approximately 33,000 tons per year per plant.

Process wastes were categorized as follows: sludges, filter residues, tars, flyash, off-quality product, and other. These process wastes were found to be extremely variable in quantities generated, with some large responses considerably influencing the average value. The largest quantities of process wastes reported were filter residues and sludges, with average waste quantities of 43,000 and 25,000 tons per year, respectively for those plants reporting these waste categories. Other average quantities reported were tars at 600 tons per year, flyash at 22,000 tons per year, off-quality product at 960 tons per year, and other process wastes at 990 tons per year.

The 28 in-depth plant visits confirmed, in most cases, the results obtained from the mail survey.

The survey showed that non-process waste generation is generally a function of plant size, in terms of employees; i.e., the larger the plant, the more waste generated. The generation of process waste, however, is not necessarily related to plant size, but is probably more closely related to the types and quantities of industrial chemicals produced and the processes employed. The quantity of solid waste generated by a particular chemical production process was found to be influenced by a number of parameters related to processing raw materials and operations. The five which seemed to be the most prominent were: (1) total production volume; (2) purity of raw materials; (3) efficiency of reaction; (4) general maintenance and (5) process control.

TABLE 1

SUMMARY OF DISPOSAL COSTS AND SOLID WASTE GENERATION

AVERAGE RESPONSE TO MAIL SURVEY

Solid waste type	Disposal cost (weighted $/t)	Average generation (tons)	Total yearly disposal costs
Non-process waste	$14.10	690	$ 9,730
Process waste	4.10	33,000	135,000
Total (weighted)	4.30	33,700	145,000

The survey indicated that industrial chemical plants expect future solid waste generation to increase significantly. Present generation of sludges and filter residues is expected to increase by 50 percent by 1975, due mainly to increased production rates. New sources of process waste generation, such as additional chemical production processes, will also add to the increase in plant process waste generation. Other factors which may influence future solid waste quantities are air and water pollution regulations and the success of chemical salvage operations.

Management of solid wastes at industrial chemical plants involves large annual operating expenditures. The average cost of disposal (including collection) of non-process combustible materials, as indicated by the mail survey results, was $32.80 per ton. Small plants exhibited the highest per ton cost for combustibles. The corresponding cost for non-process noncumbustible waste was $23.80 per ton, with extra large plants incurring the highest per ton cost. The weighted average cost for all non-process waste was $14.10 per ton.

Disposal costs for process wastes were found to be highly variable from plant to plant. The overall average for process waste was $44.70 per ton, computed as the average of each plant's dollar per ton cost. The weighted average cost was considerably less, at $4.10 per ton. The effect of quantity of solid waste on unit disposal cost is dramatically illustrated by the substantial difference between these figures. Using the weighted average disposal cost and the average waste quantities for all wastes, the average annual cost for management of solid wastes at typical industrial chemical plants is $145,000.

The average responses to the mail survey for management system characteristics are summarized on Table 2. The source areas for non-process combustible and noncumbustible waste are fairly evenly divided between plant production and non-production areas. The majority of salvageable metal is

TABLE 2
SUMMARY OF MANAGEMENT SYSTEM CHARACTERISTICS
MEAN RESPONSES TO MAIL SURVEY*
(A) NON-PROCESS WASTE

			Wastes					
			Combustibles (%) (paper, wood, bags, etc.)		Noncombustibles (%) (glass, drums, etc.)		Salvageable metal (%)	
Source area	Percent production		49		58		67	
	percent non-production		51		42		33	
Storage	Containers	Bulk	55		52		35	
		Compaction	4		3		0	
	Casual		22		27		51	
	Multiple		16		11		10	
	Other		3		7		4	
Storage period, days			10		22		119	
Ultimate disposal site	Disposition		on-site	off-site	on-site	off-site	on-site	off-site
	Percent		35	64	33	66	-	-
Ultimate disposal method	Landfill		43		73		-	
	Incineration		25		0		-	
	Other (open burning, dump, etc.)		dump 13 open 5	other 14	dump 13 other 14		- -	
Agency for off-site disposal			govt. 52 capt. 2	private 44 mult. 2	govt. 47 capt. 2	Private 50 mult. 1	-	

TABLE 2 (continued)

SUMMARY OF MANAGEMENT SYSTEM CHARACTERISTICS
MEAN RESPONSES TO MAIL SURVEY*
(B) PROCESS WASTE

Storage (percent)	Container	59
	Casual	11
	Ponds	14
	No storage	16
Storage period (days)		74
Transport method (percent)	Truck	76
	Pipeline	22
	Barge	1
	Rail	1
Disposal (percent)	On-site	39
	Off-site	61
Nature off-site disposal (percent)	Captive	8
	Private contract	70
	Government	22
Disposal method (percent)	Land disposal	72
	Incineration	8
	Lagoon	10
	Other	10

Note:
Government (govt.)-Sites owned by federal, state and local government
Captive (capt.)-Sites owned by the chemical plant.
Private-Sites owned by a private individual (waste disposal contractor).
Multiple (mult.)-Use of more than one type of site as listed above.

*Percentages shown relate to the proportion of those plants responding to the particular questions.

generated in production areas. Over 50 percent of the non-process waste is stored in containers, and very little use of compaction was reported. Storage periods for combustible waste were well over one week, and for noncombustible, over three weeks. Sixty percent or more of nonprocess waste was disposed of off-site, and approximately 50 percent is disposed of at government facilities. Landfill is the dominant disposal method, but 13 percent reported dumps and 5 percent burned combustibles in the open.

Process waste management characteristics are somewhat similar to those of non-process waste with over 50 percent stored in containers and 56 percent disposed of off-site, while land disposal is the dominant disposal method for each. The mean storage period for all process waste, however, is considerably longer at well over two months, and only 30 percent of the process waste disposed of off-site is at government facilities. It is significant to note that about half of the process wastes reported were disposed of by parties other than the plants themselves.

Efforts to control the quantity of solid waste produced by industrial chemical plants should be directed first towards reduction of solid waste generation at the source, i.e., the basic process operations. Once a solid waste is generated, however, two alternatives to its disposition exist--disposal or salvage. The disposal methods used for process wastes are essentially the same as those utilized for municipal refuse, i.e., landfill and incineration. New, more effective methods must be developed for disposal of these process wastes emphasizing abatement of environmental pollution, reduction of the waste to the smallest possible volume, and recovery of valuable constituents within the waste.

It is more desirable to salvage the waste through recycling, recovery, and utilization. The variable characteristics of process waste, however, dictate that salvage possibilities and procedures be developed or adopted by each plant to suit its own individual wastes. Prospects for solid waste salvage will increase if private contract disposal companies are successful in obtaining large process waste quantities amenable to centralized reprocessing.

Observers visited a number of plants with exceptionally well-designed and controlled disposal facilities; the potential for pollution was minimized at these plants. The majority of plant disposal operations, however, were potentially capable of polluting either air, water, or land. This study recommends that guidelines for the disposal of chemical process waste be developed, detailing the best procedures for disposal of sludges, filter residues, tars, etc. by means of the common currently available disposal methods: landfill, incineration, lagooning, etc. These guidelines would immediately assist this industry in improving its disposal practices to minimize adverse environmental effects.

SECTION TWO: INTRODUCTION

This document is the final report on a national industrial solid waste management study of the industrial chemical industry conducted for the solid waste management program of the U.S. Environmental Protection Agency under contract No. CPE 69-5. The study program was initiated by The Travelers Research Corporation and has been completed by The Research Corporation of New England (TRC), formerly the Environmental Quality and Waste Management Department of The Travelers Research Corporation.

The program's objective was to study and evaluate solid waste management practices in the industrial chemical industry by surveying manufacturing processes dealing with the manufacture of industrial chemicals. For purposes of establishing program scope, the study was to be limited to Standard Industrial Classification (SIC) 281.

The program was conducted as one of a series sponsored by the Federal solid waste management program to obtain basic information regarding the nature and dimensions of the solid waste problem in a number of industrial areas. Industrial solid wastes are, by definition, any discarded solid materials resulting from an industrial operation or coming from an industrial establishment. They include processing waste, general plant waste, packaging and shipping waste, office waste, and cafeteria waste.

The study was carried out primarily by means of direct contact with industrial chemical industry manufacturing establishments. This was accomplished by a mail survey and by plant visits. Simultaneously available information on industry statistics, technology, future plans, and waste disposal practice were obtained from a number of traditional sources and analyzed. The mail survey responses were programmed for computer analysis, and the plant visit data were used both for confirmation of the mail results and for detailed

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insight into industry solid waste practices.

The study was initiated in May 1969 with a pilot plant visit program. During this first step, selected industry representatives and plants assisted in the development of the questionnaire format for the mail survey. During these early interviews, it became apparent that the scope of the study had to be limited. The industry representatives were quite firm in their position that data on company or plant fiscal matters and production quantities would not be made available. It was also apparent that responses to questionnaires on various environmental matters had become a very time-consuming task for many plants, and that an overly comprehensive questionnaire would very likely be ignored. It was strongly suggested that the questionnaires be restricted to queries regarding solid wastes and that they be kept reasonably brief.

A further and more significant finding of the pilot study was the need to restrict the level of detail applied to the identification of specific chemical solid wastes. The complexity of the industry in its many manufacturing processes and its myriad products and wastes made it apparent that the identification of individual wastes would be out of the question except in isolated instances. In many cases the industry itself does not know the specific chemical identification of a waste stream, since many are mixtures of residues from several processes. Thus the most pertinent accomplishment of the pilot study portion of the program was the adoption of several general process waste categories to be used in the balance of the program. This step and the formulation of the questionnaire represented a compromise which held the promise of maximizing the industry's response to the program.

The questionnaire formats were submitted for Budget Bureau approvals in September 1969. The approvals were received in January 1970, and the program was resumed on February 1, 1970. Mail questionnaires were distributed on

March 1, 1970, followed by the completion of the plant visits in August 1970. Response to both was slower than expected. Many larger corporations adopted a comprehensive review and approval procedure, delaying their plants' responses for several months. Arrangements for plant visits were also difficult to accomplish, not necessarily because of resistance on the part of the plants, but simply because of scheduling problems. The overall response provided a return of 12 percent in usable replies, and this was considered adequate for the realization of the objectives of the study. Response tabulation and data analysis were carried out through November 1970, and report preparation through January 1971.

The report consists of eight sections and several appendices. Section Three describes the nature of the industrial chemical industry and its position in the national economy. This discussion was included as a necessary part of the contract to provide those unfamiliar with the industry with a basis for understanding the nature and scope of the industry's solid waste problems. Section Four defines the solid waste categories of the industry and their sources.

Section Five reviews a number of chemical processes in detail and traces their potential for generation of solid wastes. Solid waste generation in this industry is fundamental to the chemical manufacturing process. In the production of chemicals, generation of solid waste varies both in quantity and composition with the manufacturing process used. It can also vary within the same manufacturing process due to such factors as the raw material used, temperature conditions, design of equipment, and choice of catalyst. In order to adequately describe this variability to those unfamiliar with chemical engineering, it was deemed necessary to provide a discussion of the nature of chemical manufacture.

Those people familiar with the industrial chemical industry will be mostly interested in Sections Six, Seven and Eight. Section Six presents an analysis of current solid waste management practices in the industrial chemical industry, while Section Seven presents the results of the survey program both from mailed questionnaires and plant visits. Section Eight provides a discussion of the program findings.

SECTION THREE: THE INDUSTRIAL CHEMICAL INDUSTRY

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SECTION THREE: THE INDUSTRIAL CHEMICAL INDUSTRY

Scope of the Industry

The industrial chemical industry, which manufactures a wide variety of chemicals and chemical products, is one of a number of sub-industries comprising the broad chemical industry. The parent chemical industry includes all those industries whose manufacturing operations are composed of processes which are predominantly chemical.

In its industrial classification, the Bureau of the Census has grouped the entire chemical industry into one classification called Chemicals and Allied Products. This group comprises all those establishments producing chemicals and those producing finished chemical products. The industry, Standard Industrial Classification (SIC) #28, is defined by the Bureau as follows:

> This major group includes establishments producing basic chemicals, and establishments manufacturing products by predominantly chemical processes. Establishments classified in this major group manufacture three general classes of products: (1) basic chemicals such as acids, alkalies, salts, and organic chemicals; (2) chemical products to be used in further manufacture such as synthetic fibers, plastics materials, dry colors and pigments; (3) finished chemical products to be used for ultimate consumption such as drugs, cosmetics, and soaps; or to be used as materials or supplies in other industries such as paints, fertilizers, and explosives. The mining of natural rock salt is classified in mining industries. Establishments primarily engaged in manufacturing nonferrous metals and high percentage ferroalloys are classified in Major Group 33; silicon carbide in Major Group 32; baking powder, other leavening compounds, and starches in Major Group 20; and embalming fluids and artists' colors in Major Group 39. Establishments primarily engaged in packaging, repackaging and bottling of purchased chemical products, but not engaged in manufacturing chemicals and allied products, are classified in trade industries.

Appearing under the broad heading of chemicals and allied products, SIC #28, are eight major categories as follows:

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SIC No.	Major Categories
281	Industrial inorganic and organic chemicals
282	Plastics materials and synthetic resins, synthetic rubber, synthetic and other man-made fibers, except glass
283	Drugs
284	Soap, detergents, and cleaning preparations, perfumes, cosmetics and toilet preparations
285	Paints, varnishes, lacquers, enamels, and allied products
286	Gum and wood chemicals
287	Agricultural chemicals
289	Miscellaneous chemical products

This study is concerned with solid waste generated by industries producing chemicals within the first category only, SIC #281, Industrial Inorganic and Organic Chemicals, sometimes called Basic Chemicals, or Industrial Chemicals. Organic chemicals have been defined as those compounds containing carbon atoms in a form similar to those in plant and animal matter, and conversely, inorganic chemicals are defined as compounds usually not containing carbon (except compounds such as carbides and carbonates) but derived from atmospheric gases, minerals, water, and other matter that was never, of itself, a part of living organisms.

Industrial chemicals, SIC #281, is the largest of the eight subgroups under SIC #28 Chemicals and Allied Products. In 1967 its value of shipments amounted to over $14 billion, or just over 33 percent of the total value of shipments for the Chemical and Allied Products industry. Table 3 shows the relationship, in terms of value of shipments, between the industrial chemical industry and the other subgroups in SIC #28. The basic chemicals necessary to produce the chemical products included in the other subgroups are supplied primarily by this industry.

The industrial chemical industry, SIC #281, is composed of basic chemical manufactures and does not include producers of allied chemical products. Processes and plants producing the following material are not included in SIC #281

TABLE 3

PERCENT DISTRIBUTION OF VALUE OF SHIPMENTS FOR INDUSTRIES IN THE CHEMICALS AND ALLIED PRODUCTS GROUP (1967)*

SIC No.	Chemical group	Value of shipments Millions of dollars	Value of shipments % Total
281	Industrial inorganic and organic chemicals	14,100	33.0
282	Fibers, plastics, rubber	7,430	18.0
283	Drugs	5,260	13.0
284	Cleaning and toilet goods	6,450	15.0
285	Paints and varnishes	2,920	7.0
286	Gum, wood chemicals	224	0.0
287	Agricultural chemicals	2,690	6.5
289	Miscellaneous chemical products	3,110	7.5
	Total	42,200	100.0

*From Reference #67.

and are therefore excluded from this study: pesticides; medicinal chemicals and medicines; wood distillation products; naval stores; cosmetics; plastics such as polyvinyl chloride, polyethylene, polypropylene, and polyurethanes; synthetic rubber; rayon; and other synthetic fibers such as nylon, polyesters, acrylics and modacrylics, vinyls, etc.; paints; and drugs. In addition, the following basic "raw material" industries that have been included in other SIC classifications are not included in this study, namely: industries manufacturing coal tar crudes in chemical recovery ovens (coking plants); petroleum refineries; and plants primarily engaged in mining, milling, or otherwise preparing naturally occurring ores and other similar materials.

To further classify the industrial chemical industry, the Bureau of the Census has defined six subcategories within SIC #281 as follows:

SIC #2812: Establishments primarily engaged in manufacturing alkalies and chlorine;

SIC #2813: Manufacture of industrial gases, including acetylene, carbon dioxide, hydrogen, nitrogen, etc.;

SIC #2815: Manufacture of cyclic intermediates, dyes, organic pigments, and cyclic crudes. This subcategory includes lakes and toners; coal tars; derivatives of benzene; toluene; and other cyclic chemical products of medium and heavy oil, such as creosote oil, naphthalene and anthracene;

SIC #2816: Manufacture of inorganic pigments, including iron colors, lead pigments, titanium pigments, and zinc oxide pigments;

SIC #2818: Manufacture of organic chemicals not included in the previous categories. This subcategory includes a wide variety of chemicals, solvents, polyhydric alcohols, synthetic perfume and flavoring materials, rubber processing chemicals, plasticizers, and synthetic tanning agents;

SIC #2819: Manufacture of inorganic chemicals not included in the previous categoeries, such as inorganic salts of sodium, potassium, aluminum, calcium, etc.; inorganic compounds such as alums and ammonia compounds, rare earth metal salts and elemental bromine, fluorine and alkali metals.

The industries included in these six subcategories are the basis of this solid waste study. A more detailed list of the chemicals whose manufacture is included in these subcategories will be found in the appendix Table 43.

There is often a marked overlap of manufactured chemicals, allied products, and even nonchemical products in many chemical plants. Two prominent examples of this overlap which occur in many plants are in plastics and synthetic fibers. All of the basic chemicals used to produce these two products are included in SIC #281, including phenol, plasticizers, and styrene for plastics; adipic acid, sebacic acid, and other acids for nylon; acrylonitrile for acrylics; and others, but the plastics and fibers themselves are not included. Every effort was made when visiting plants and analyzing mail questionnaire returns to include only solid wastes associated with industrial chemical, SIC #281, production.

Evolution of the Industrial Chemical Industry in the United States

During the last two centuries, the United States has progressed from a country with little or no chemical production to a world leader in chemical technology and sales. The availability of raw materials, both domestic and imported, the availability of power, and the demand for chemical products have helped to shape the types and quantities of chemicals produced, the processes used, and the location of chemical centers.

The use of chemical products began very early in young America. The early colonists produced simple tanning, bleaching, and dyeing products. As early as 1635, industry in Boston was producing saltpeter for gunpowder and alum for tanning.

The colonists established an export trade with England in the early 18th century for potash and naval stores. One of the causes for America's drive for independence was Parliament's forced duties on white lead and other chemical products.

It was the 19th century, however, that saw the real beginnings and growth of chemical production. Chemical plants sought to locate themselves in those geographic areas where natural raw materials for chemical production existed. Thus, as the industry grew, those areas rich in these materials became the centers for chemical production.

In 1802 Wilmington, Delaware, was selected for the site of a powder mill by a French pupil of the chemist Lavoisier. This student was Euthere Irenee du Pont who founded the company which now bears his name. Philadelphia was the site of the first sulfuric acid plant built in 1793. This first plant used the batch lead chamber process, but by 1829, the first continuous production operation was installed. By 1829, Philadelphia had developed into a chemical center with merchants producing white lead, acetic acid, linseed oil, and paste pigments.

St. Louis industrialists began production of red lead in 1811, and in the same year, the gold rush brought acid manufacturing to the West Coast to meet gold refining needs. In 1850 the agricultural chemical industry was born, and sulfuric acid plants moved south to the source of phosphate rock. Salt and lime deposits at Syracuse, New York, were exploited in 1884 when an ammonia-soda plant using the Solvay process was built. One soda ash plant built over Michigan salt deposits and another built over salt domes in southwest Virginia in 1895 helped to bolster production of alkalies which were previously imported from Great Britain. In 1896 the first cholorine process was established by Herbert H. Dow, and bromine was extracted from Michigan brine deposits.

At the same time that the chemical industry was utilizing Michigan's brine deposits, Niagara Falls, New York was developing into a chemical center, primarily due to the availability of cheap hydroelectric power. Niagara Falls became a center for production of chlorine, caustic soda, sodium and potassium chlorates, yellow phosphorus, and calcium carbide.

At the beignning of the present century, chemical production was primarily inorganic. Allied products, such as patent medicines, paints and varnishes, and soap and fertilizers were the largest commodities. The primary industrial chemicals at this time were soda ash, sulfuric acid, caustic soda, nitric acid, and glycerin.

Department of the organic chemical industry occurred during World War I. The German supply of organic chemicals upon which the U.S. depended were cut off, and we had to develop our own production capabilities. A nitric acid plant using cyanamid-derived ammonia was built in 1916 at Warners, New Jersey, to help manufacture the large quantities of explosives required during World War I. In 1907 at Joliet, Illinois, Dr. Heinrich Koppers developed an apparatus and process for economical recovery of chemicals from coal in the coke-making process, and the U.S. organic chemical industry was underway.

After World War I, growth in the chemical industry progressed rapidly as America moved toward the 20th century technical leadership which required greater and greater quantities of chemicals. Early in this period the industry also recognized the importance of research to the development of new chemicals. This awareness has led to the immense quantities and varieties of chemicals presently produced. Today the American chemical industry produces nearly 50 percent of the free world's output of chemicals. (3,13)

Geographic Distribution of the Industry

The industrial chemical industry is concentrated in certain areas of the country rather than randomly distributed throughout the nation. These areas coincide with those of high population concentration and other industrial and commercial activity, along with easy access to raw materials necessary for chemical manufacture. In addition, the industry requires a source of inexpensive power, a good transportation system, and people for a work force.

Various sections of the country were evaluated to determine areas of intensive industrial chemical manufacture. Regional evaluation was based on the U.S. Bureau of the Census regions (Figure 1). Concentration of industrial chemical manufacture was evaluated from "value added by manufacture" as reported by the Bureau of the Census. Value added by manufacture is obtained by subtracting the total cost of materials (including supplies, fuel, electric energy, cost of re-sales, and miscellaneous receipts) from the value of shipments (including re-sales) and other receipts, and adjusting the resulting amount by the net change in finished products and work-in-process inventories between the beginning and end of the year. This method is considered to be the best value measure for comparing the relative economic importance of manufacturing among industries and geographic areas.

The west-south-central, middle-Atlantic and north-central regions of the country are the areas of greatest industrial chemical manufacturing (Figure 2). These regions also contain the majority of those metropolitan areas with over $100 million in value added by manufacture for chemicals and allied products in 1967. The west-south-central region includes the cities of Dallas and Houston, the middle-Atlantic region contains the cities of New York (and surrounding New Jersey metropolitan areas), Philadelphia, Wilmington, Buffalo, Niagara Falls, and Pittsburgh, while the north-central region includes Chicago, Detroit, Cleveland, Cincinnati and Indianapolis.

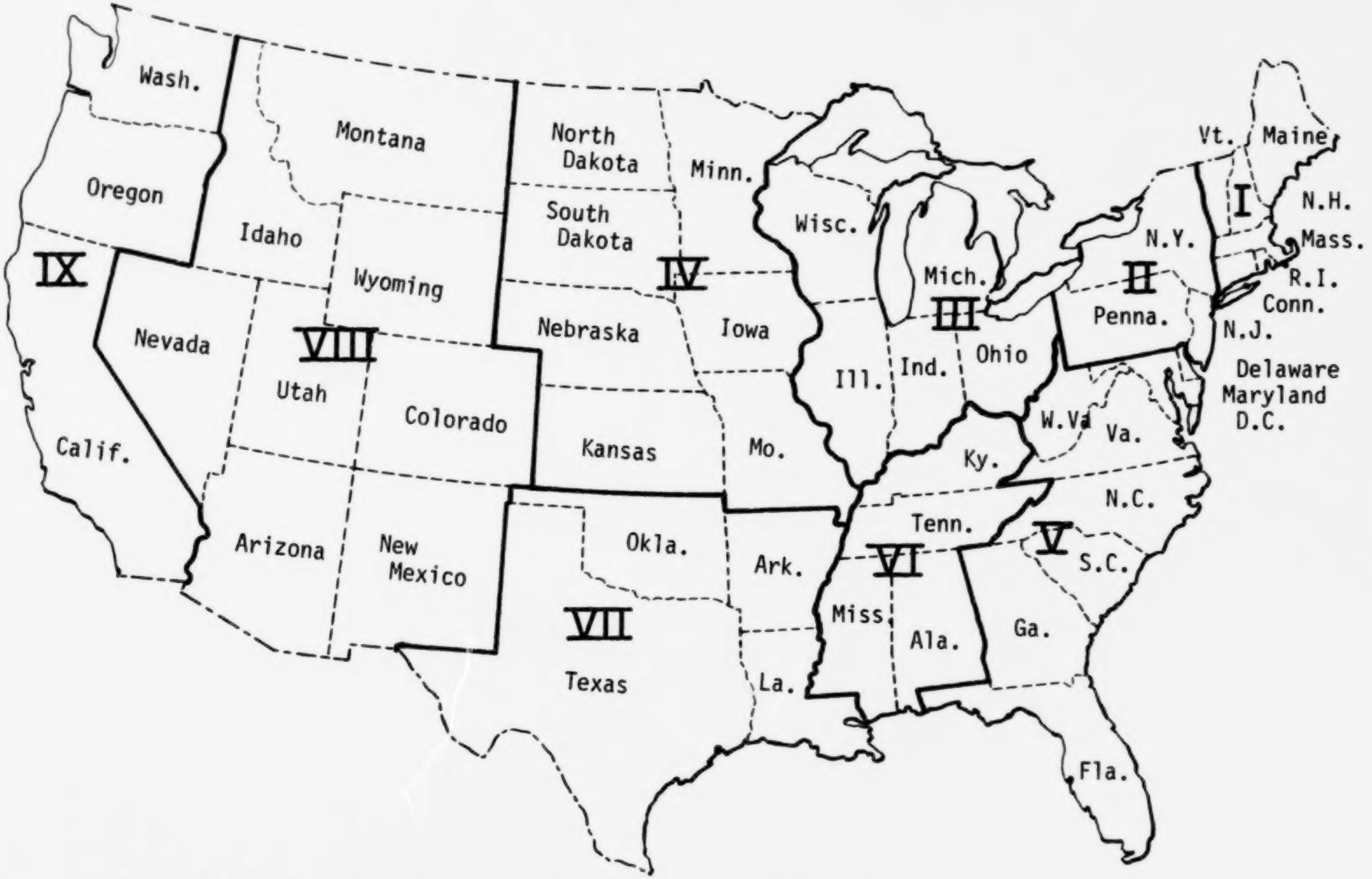
Wash.
Oregon
IX
Calif.
Nevada
Idaho
Montana
Wyoming
VIII
Utah
Colorado
Arizona
New Mexico
North Dakota
South Dakota
Nebraska
Kansas
IV
Minn.
Iowa
Mo.
Okla.
VII
Texas
Ark.
La.
Wisc.
Ill.
Mich.
III
Ind.
Ohio
Ky.
Tenn.
VI
Miss.
Ala.
V
Ga.
S.C.
N.C.
Va.
W.Va
Fla.
II
N.Y.
Penna.
I
Vt.
Maine
N.H.
Mass.
R.I.
Conn.
N.J.
Delaware
Maryland
D.C.

Figure 1. U.S. Bureau of Census Regions (1969). These regions are used by the Bureau as a basis for compiling regional industrial statistics and are slightly different from the U.S. Public Health Service Regions.

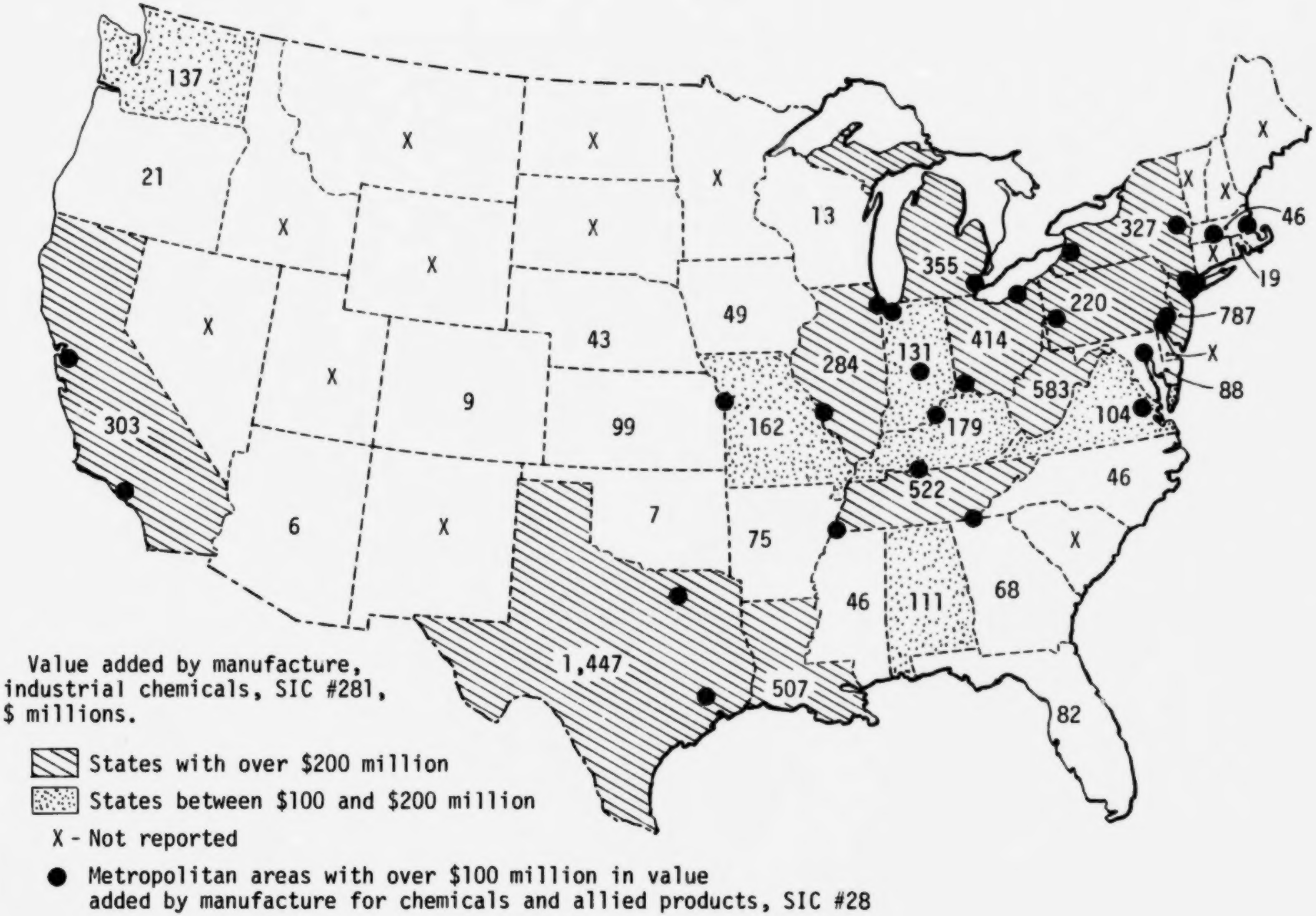
137
21
303
X
X
X
6
X
X
9
X
X
X
X
43
99
7
1,447
X
49
13
162
75
507
284
355
131
46
111
414
179
522
583
220
68
X
82
104
46
327
X
X
X
46
X
19
787
X
88
Value added by manufacture, industrial chemicals, SIC #281, $ millions.
States with over $200 million
States between $100 and $200 million
X - Not reported
Metropolitan areas with over $100 million in value added by manufacture for chemicals and allied products, SIC #28

Figure 2. Areas of concentration of industrial chemical manufacture, 1967. (From Reference #66)

Two other areas of heavy industrial chemical manufacture are the east-south-central region and the State of California. In the east-south-central region the industry is centered in West Virginia and Kentucky, while in California the industry is concentrated around the two large metropolitan areas of San Francisco and Los Angeles.

Nationally, regions containing a high incidence of industrial chemical manufacture coincide with areas of high population concentration (Figures 2 and 3). There is a tendency for those states with a high proportion of their population concentrated in urban areas to also contain substantial industrial chemical manufacturing. A listing of the ten metropolitan areas with the highest chemical manufacturing activity includes most of our largest urban areas (Table 4). Although the listing is by chemical and allied product manufacture, it is representative of the industrial chemical industry.

Another indication of basic chemical manufacturing activity is the total number of chemical plants in an area. The number of manufacturing plants with 20 employees or more (for 1967) was tabulated by region and compared to value added by manufacture. The complete table along with the states within each region can be found in the appendix. The middle-Atlantic, east-north-central, and west-south-central regions were found to have the greatest industrial chemical activity. The middle-Atlantic region contains over 24 percent of the plants in the U.S. engaged in manufacturing industrial chemicals, and over 17 percent of value added by manufacture for the industry. The east-north-central area contains over 18 percent of the plants and over 15 percent of value added by manufacture, while the west-south-central area contains over 14 percent of the plants and over 26 percent of the value added by manufacture.

The six states exhibiting the greatest concentration of industrial chemical manufacture in terms of number of plants and dollar business size are shown in Tables 5 and 6.

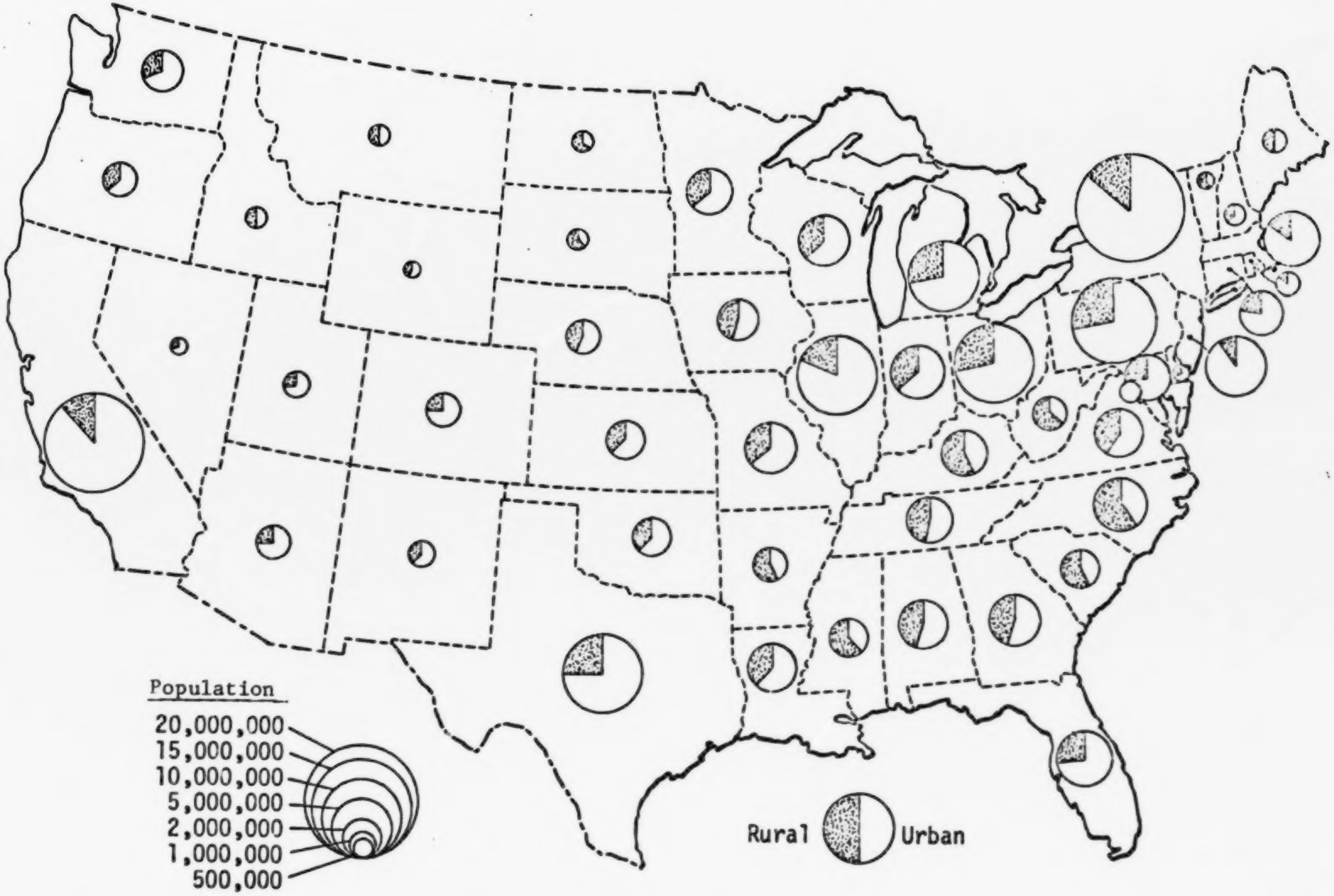
Population
20,000,000
15,000,000
10,000,000
5,000,000
2,000,000
1,000,000
500,000
Rural
Urban

Figure 3. Total U.S. population, urban and rural, by states (1960). (From 1960 Census)

TABLE 4

THE TEN METROPOLITAN AREAS WITH THE HIGHEST CHEMICAL MANUFACTURING ACTIVITY CHEMICAL AND ALLIED PRODUCTS INDUSTRY-SIC #28 (1967)*

	Metropolitan area	Value added by manufacture, millions of dollars
1.	New York, N.Y., Northeastern New Jersey standard consolicated area.	3,290
2.	Chicago, Ill., Northwestern Indiana standard consolidated area.	1,310
3.	Chicago, Ill.	1,120
4.	Newark, New Jersey	1,120
5.	Philadelphia, Penn.	1,020
6.	New York City	895
7.	Houston, Texas	836
8.	Los Angeles-Long Beach, Cal.	575
9.	Cincinnati, Ohio, Ky., Ind.	529
10.	St. Louis, Mo.-Ill.	487

*From Reference #66.

TABLE 5

THE SIX STATES WITH THE GREATEST NUMBER OF INDUSTRIAL CHEMICAL PLANTS, 1967*

	State	Industrial chemical plants (20 employees or more)
1.	New Jersey	128
2.	Texas	85
3.	California	81
4.	Ohio	70
5.	Pennsylvania	60
6.	Illinois	53

*From Reference *66.

TABLE 6

THE SIX STATES REPORTING THE HIGHEST VALUE ADDED BY MANUFACTURE FOR INDUSTRIAL CHEMICALS, 1967*

State	Value added by manufacture Millions of dollars
1. Texas	$1,450
2. New Jersey	787
3. West Virginia	582
4. Tennessee	522
5. Louisiana	507
6. Ohio	413

*From Reference #66.

Texas is second in number of plants, but has almost twice the value added by manufacture for industrial chemicals as the second highest state, New Jersey. This figure illustrates graphically the importance of natural gas and petroleum as raw materials for organic chemical synthesis.

The nature of the chemicals produced differs from region to region (Figure 4). In the middle-Atlantic region, miscllaneous organic chemicals predominate; in the east-north-central region, there is an almost equal division between organic and inorganic chemicals manufacture, while in the west-south-central region, the manufacture of organic chemicals is predominant. In the Pacific region, inorganic chemicals lead by a wide margin.

These regions have built up their chemical industry largely on the basis of raw material availability and cost. Raw materials for use in manufacturing inorganic chemicals depend to a large extent on water transportation, while oil and gas for use in making organic chemicals are generally transported by pipe line.

Characteristics of the Producing Companies

The companies which produce industrial chemicals range from small independent companies with one or two products to giant multiplant corporations employing thousands of people and making thousands of products. Chemical sales are dominated by the large multiplant corporations, many of which produce chemicals and allied products along with non-chemical products. The economy of scale concept (large units operate more economically) seems to be generally applicable for production of industrial chemicals. Thus the large companies produce chemicals at lower prices in most instances and thereby obtain a larger share of the market.

The major chemical producers include some of the largest corporations in

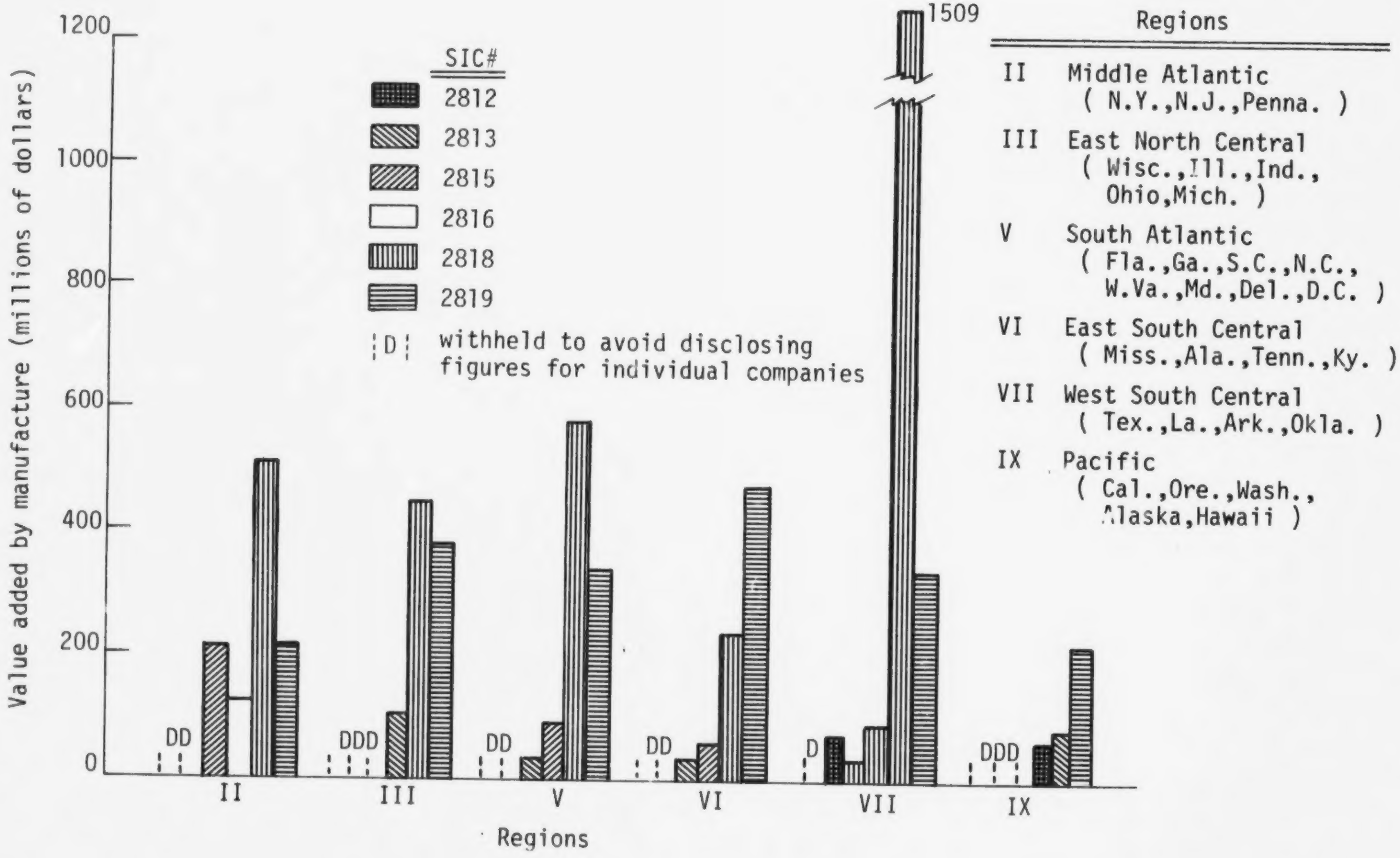

Figure 4. Manufacture of industrial chemicals by SIC subgroup for selected regions, 1967. (From Reference #68)

TABLE 7

THE FIFTY LARGEST COMPANIES IN CHEMICAL SALES
IN THE UNITED STATES*

Rank	Company	Chemical sales ($ million)	Total income** ($ million)	Chemical sales as percent of total income	Company S.E.C. class***
1	Du Pont	$3250	$3481	94%	281
2	Monsanto	1711	1810	94	281
3	Union Carbide	1675	2686	62	281
4	Dow Chemical	1450	1723	84	281
5	W. R. Grace	958	1761	54	281
6	Standard Oil (N.J.)	933	15873	6	291
7	Celanese	917	1256	73	281
8	Allied Chemical	869	1278	68	281
9	Hercules	639	718	89	281
10	FMC	625	1387	45	281
11	Occidental Petroleum	571	1815	31	509
12	American Cyanamid	522	1040	55	281
13	Shell Oil	513	4008	13	291
14	Eastman Kodak	507	2644	19	383
15	Stauffer Chemical	478	478	100	281
16	Uniroyal	476	1436	33	301
17	Phillips Petroleum	447	2130	21	291
18	Rohm and Haas	423	428	99	281
19	Mobil Oil	417	7089	6	291
20	Cities Service	358	1461	25	291
21	Borden	354	1681	21	202
22	Standard Oil (Ind.)	342	3994	9	291
23	Ashland Oil****	342	1082	32	291
24	Continental Oil	333	2443	14	291
25	IMC	332	502	66	287
26	Ethyl Corp	331	512	65	281
27	Gulf Oil	315	5657	6	291
28	Diamond Shamrock	314	528	59	281
29	Olin	298	1011	29	281
30	American Can	278	1633	17	341
31	National Lead	275	876	32	285
32	PPG Industries	261	1058	25	321
33	Air Reduction	254	440	58	281

TABLE 7, continued

Rank	Company	Chemical sales ($ million)	Total income** ($ million)	Chemical sales as percent of total income	Company S.E.C. class***
34	US Steel*****	250	4609	6	331
35	Tenneco	242	2101	12	291
36	B. F. Goodrich*****	240	1144	21	301
37	American Enka	239	239	100	281
38	Witco Chemical	221	224	99	281
39	Pennwalt	208	407	51	281
40	Pfizer	200	736	27	283
41	Koppers	199	449	44	281
42	Air Products	185	205	90	281
43	Chemetron	179	244	73	281
44	Swift*****	170	2832	6	201
45	Reichhold	161	161	100	281
46	Goodyear*****	160	2941	5	301
47	GAF	150	571	26	281
48	Wyandotte	147	148	99	281
49	Sinclair Oil	143	1478	10	291
50	National Distillers	136	958	14	208

*From Reference #10.

**All financial data for fiscal 1968.

***According to "66 Directory of Companies Filing Annual Reports with the Securities and Exchange Commission, 1967". SEC classifications are as follows:

201	meat products
202	dairy products
208	alcoholic beverages
281	basic chemicals
283	drugs
285	allied products
287	agricultural chemicals
291	petroleum
301	tires
321	glass products
331	steel
341	metal cans
383	photo equipment
509	miscellaneous wholesaler

****Before extraordinary, non-recurring items.

*****Chemical and Engineering News estimate.

the country. Of the 500 largest industrial companies in 1963, 29 obtained approximately one-third or more of their sales from chemicals, mainly industrial chemicals.(3) A list of the 50 top firms in chemical sales for fiscal year 1968 (Table 7) was compiled by the staff of Chemical and Engineering News from data of the Securities and Exchange Commission (SEC).(10) Of these top 50 companies, four are in the top 10 companies ranked by sales in the Fortune compilation of the 500 largest industrial corporations--1968.(28) Nineteen are in the top 50, 29 are in the top 100, and all 50 appear within the Fortune top 500. The Fortune listing also showed four predominantly industrial chemical companies as members of the billion dollar sales club; these are du Pont, Monsanto, Union Carbide and Dow Chemical, and three others were very close to this mark.

The SEC classifies industries according to their predominant manufacture (Table 7). The SEC 281 classification, basic chemicals, is a broader definition than the Bureau of the Census 281. It includes industrial chemicals and gases, bulk specialty chemicals, plastic materials and resins, synthetic rubber, man-made fibers, and some fertilizer and agricultural chemicals. Even with this broad definition, however, only half of the top 50 chemical producers are classified by SEC as basic chemical producers; the other 25 are scattered among 13 other SEC groupings. An analysis of the 25 industrial chemical producers shows their combined chemical sales of $16.77 billion to be only 71 percent of their total sales. The 25 non-chemical corporations had combined chemical sales of $8,26 billion--or 33 percent of their $25.03 billion in total sales. These figures illustrate the diffuse nature of the chemical industry, in that basic chemical companies produce significant volumes of non-chemicals, and non-chemical companies, led by the major oil companies, produce large volumes of industrial chemicals.

To reflect the activity and degree of dominance of the larger companies in a particular industrial sector, the Bureau of the Census has computed production value (concentration) ratios. The total shipments in seven categories of industrial chemicals and the percentages attributed to the top 4, 8, 20 and 50 companies are tabulated on Table 8.

Four of the companies shown on the table sold 43 percent of the entire 1967 output, eight of them sold 52 percent, and the 20 largest sold 76 percent of the total. The eight largest dominated the sales by 2/3 of the total or more in the fields of alkalies and chlorine, industrial gases, cyclic compounds, intermediates and crudes, and inorganic pigments. The spread was greatest in the manufacture of organic and inorganic chemicals.

When the 2,030 plants in the various #281 classifications are examined relatively according to the number of employees (Table 9), it is interesting to note that 1,600 plants, or 79 percent of the total of 2,030, have less than 100 employees. Only 105 plants, or 5 percent of the total have more than 500 employees, and less than half of these have over 1,000 employees. These figures explain why industrial chemicals have remained relatively stable in price over the years. Large-scale operation and automation have reduced the labor portion of manufacturing cost to a minimum.

Practically all of the plants producing industrial gases are small; 98 percent have fewer than 100 employees. These plants are located throughout the country, close to their markets, since transportation costs for these gases are high.

Role of the Industry in the Economy

The chemical industry is a major segment of U.S. industry and produces the basic building-block chemicals used either directly or indirectly in the manufacturing activities of almost all other industries. Between 1958 and

TABLE 8
PERCENT OF VALUE OF SHIPMENTS ACCOUNTED FOR BY THE LARGEST COMPANIES IN THE INDUSTRIAL CHEMICAL INDUSTRY: 1967 AND EARLIER YEARS*

Code	Industry and year	Companies	Value of shipments				
			Total	Percent accounted for by			
		(number)	(million dollars)	4 Largest companies	8 Largest companies	20 Largest companies	50 Largest companies
	INDUSTRIAL CHEMICALS			A "company" is defined for this purpose as the total of its industrial establishments.			
2812	Alkalies .... 1967..	19	720	63	88	100	(X)
	and .... 1966..	(NA)	783	63	88	(NA)	(NA)
	chlorine .... 1963..	19	652	62	88	100	(X)
	.... 1958..	18	488	64	89	100	(X)
	.... 1954..	17	400	69	90	100	(X)
	.... 1947..	18	209	70	93	100	(X)
2813	Industrial .. 1967..	113	589	67	84	95	99
	gases .... 1966..	(NA)	550	72	88	(NA)	(NA)
	 1963	104	425	72	86	95	99
	 1958	111	232	79	88	94	98
	.... 1954..	101	168	84	88	93	(NA)
	.... 1947..	69	93	83	88	94	(NA)
	.... 1935..	(NA)	(NA)	79	87	(NA)	(NA)
2815	Cyclic .... 1967..	115	1,597	45	64	83	97
	intermediates 1963..	120	1,213	53	71	88	99+
	and						
	crudes						
2816	Inorganic.... 1967..	65	549	59	78	95	99+
	pigments 1966	(NA)	582	64	83	(NA)	(NA)
	.... 1963..	69	485	68	84	96	99+
	.... 1958..	67	403	69	83	96	99+
	.... 1954..	73	371	67	83	96	(NA)
2818	Industrial .. 1967..	339	6,380	45	58	75	92
	organic .... 1966..	(NA)	6,540	46	60	(NA)	(NA)
	chemicals ... 1963..	343	4,840	51	63	79	93
	n.e.c. .... 1958..	250	3,070	55	70	85	96
	 1954	202	2,200	59	73	87	(NA)
2819	Industrial .. 1967..	408	4,250	27	43	64	85
	inorganic ... 1966..	(NA)	3,840	29	46	(NA)	(NA)
	chemicals ... 1963..	404	3,490	31	49	71	88
	n.e.c. .... 1958..	(NA)	2,610	34	50	(NA)	(NA)

(NA) not available (X) not applicable

*From Reference #69.

TABLE 9
SIZE OF CHEMICAL PLANTS BY NUMBERS OF EMPLOYEES (1967)
(INCLUDING PLANTS WITH LESS THAN 20 EMPLOYEES)*

SIC category	Total no.plants	Number of plants with an average of							
		1-100 employees		100-500 employees		500-1000 employees		over 1000 employees	
		number	percent	number	percent	number	percent	number	percent
281 Industrial chemicals	2032	1600	79	327	16	57	3	48	2
2812 Alkalies & chlorine	44	14	32	18	41	6	13.5	6	13.5
2813 Industrial gases	507	494	98	12	2	1	-	-	-
2815 Cyclic intermed. & coal tar crudes	177	113	64	50	28	7	4	4	4
2816 Inorganic pigments	98	71	73	23	23	1	1	3	3
2818 Organic chemicals n.e.c.	488	339	70	108	22	21	4	20	4
2819 Inorganic chemicals n.e.c.	718	569	79	116	16	21	3	12	2

1967, shipments of the chemical and allied products industry have been at levels equivalent to over 5 percent of gross national product.(8) In 1969 the chemicals and allied products industry accounted for over 2 percent of the national income for all industries ($16.3 billion out of $769.5 billion), and represented almost 18 percent of national income for the nondurable goods industry ($86.9 billion).(60)

The position of the chemical and allied products industry, and its largest segment, the industrial chemical industry, relative to all U.S. industry is shown in Table 10. Although the chemical and allied products industry accounts for only 4.4 percent of all manufacturing employees, the value of the products produced and its dependence on large sophisticated production units, is reflected by its contribution of 7.6 percent of the value of all shipments, 14 percent of all new capital expenditures, and 9.1 percent of the value added by manufacture for all industry. Of the 21 Census industrial groups, 11 had a greater total employment than the chemical and allied products industry, but only four industries (namely: food and kindred products; machinery, except electrical; electrical equipment and supplies; and transportation equipment) had a greater value added by manufacture. Only the above four, plus the primary metals industry, had a greater value of shipments, and only the primary metals industry had greater new capital expenditures. This last fact illustrates the importance of the chemical industry to the existence and growth of many non-manufacturing industries such as the construction industries and its allied businesses.

Almost a third of the value added by manufacture of the chemical and allied products industry is contributed by the industrial chemical industry, and a large 43 percent of the new capital expenditures are attributable to the industrial chemical industry. Compared to all manufacturing industry, industrial chemicals account for 1.3 percent of all employees, 2.5 percent of the value of shipments, 3 percent of value added by manufacture, and 6 percent of new

TABLE 10

ECONOMIC POSITION OF THE INDUSTRIAL CHEMICAL INDUSTRY (1967)*

Industry	All employes			Value added by manufacture			Value of shipments			New capital expenditures		
	Number (Thous)	Percent of all industry	Percent of chem. & allied products	Total dollars (mill.)	Percent of all industry	Percent of chem. & allied products	Total dollars (mill.)	Percent of all industry	Percent of chem. & allied products	Total dollars (mill.)	Percent of all industry	Percent of chem. & allied products
All manuf. industry	19,400	-	-	$259,000	-	-	$555,000	-	-	$20,300	-	-
Chemical and allied products industry	834	4.4	-	$ 23,400	9.1	-	$ 42,200	7.6	-	$ 2,830	14.0	-
industrial chemical industry	249	1.3	29.2	$ 7,700	3.0	33.0	$ 14,100	2.5	33.4	$ 1,220	6.0	43.0

*From Reference #67 and 68.

capital expenditures. Only six of the 20 major industry groups had greater new capital expenditures than the industrial chemical industry, and it contributed more to value added by manufacture than half of the major industry groups.

Growth of the Industry

The growth rate of the chemicals and allied products industry during the sixties has been above average. Value added by manufacture grew 90 percent over the period from 1958 to 1967, compared to an 80 percent growth of all manufacturing industry. From 1963 through 1968, the average annual growth rate of shipments of this industry was 8 percent. In 1969 the growth fell to 6 percent, with this same comparatively low rate of growth forecast for 1970.(9)

Industrial chemical industry growth, as shown on Table 11 for the 1958-1967 period at 83 percent, was not as large as that of its major group, and just slightly greater than for all manufacturing industries. Organic chemicals SIC 2818, however, showed a 107 percent increase in value added by manufacture over the same period, while inorganic chemicals, SIC 2819, showed only a 56 percent increase. More recently, the increase in value of shipments for industrial chemicals has been greater than that of chemicals and allied products. In 1969, industrial chemical shipments increased 8 percent to $16.6 billion. This figure is expected to increase about 7 percent to $17 billion in 1970. Continuation of this 7 percent annual increase has been forecast through 1975. The largest contributor to this recent growth is organic chemical shipments. In 1969 miscellaneous organic chemicals showed an increase of 11 percent in value of shipments. They are projected to show an 8 percent increase to $8.9 billion in 1970. This is an overall increase of 35 percent from the $6.58 billion in 1958.(9)

Among the organic chemicals, the fastest growing group is the miscellaneous

TABLE 11

GROWTH STATISTICS FOR THE INDUSTRIAL CHEMICAL INDUSTRY, 1958-1967*

	All employees			Value of shipments (millions of dollars)			Plants			Value added by mfr. (millions of dollars)		
	1958	1963	1967	1958	1963	1967	1958	1963	1967	1958	1963	1967
Industrial chemicals (SIC #281)	238,000	237,000	249,000	7,980	11,100	14,100	1,650	1,870	2,030	4,210	6,170	7,730
% increase from 1958	---	-0.6	+4.5	---	+39.1	+76.3	---	+13.1	+22.8	---	+46.4	+83.5
Alkalies & chlorine (SIC #2812)	20,500	19,600	19,200	504	652	720	34	38	44	306	389	419
% increase from 1958	---	-4.0	-6.2	---	+29.4	+42.8	---	+5.9	+29.4	---	+27.1	+36.9
Industrial gases (SIC #2813)	10,600	9,810	10,300	277	425	589	491	456	507	174	260	401
% increase from 1958	---	-7.8	-3.2	---	+53.4	+112.6	---	-7.1	+2.6	---	+49.4	+130.5
Cyclic intermediates (SIC #2815)	28,300	27,700	30,000	934	1,210	1,600	115	141	177	403	605	729
% increase from 1958	---	-2.0	+6.0	---	+29.8	+70.9	---	+22.6	+53.9	---	+50.1	+80.9
Inorganic pigments (SIC #2816)	11,400	11,500	12,600	418	485	549	99	96	98	236	286	316
% increase from 1958	---	+1.5	+10.8	---	+16.0	+31.3	---	-3.0	-1.0	---	+21.2	+33.9
Organic chemicals (SIC #2818)	77,400	85,500	95,100	3,100	4,840	6,380	334	464	488	1,730	2,730	3,570
% increase from 1958	---	+10.4	+23.4	---	+56.2	+105.8	---	+38.9	+46.1	---	+58.0	+107.1
Inorganic chemicals (SIC #2819)	89,900	82,400	81,200	2,750	3,490	4,250	580	674	718	1,470	1,900	2,290
% increase from 1958	---	-8.3	-9.6	---	+26.8	+54.2	---	+16.2	+23.8	---	+29.5	+56.2

*From Reference #68.

acyclic organic chemicals commonly called "petrochemicals". Other rapidly growing chemicals are gasoline and lubricating oil additives, photographic chemicals, ore flotation reagents, flavor and perfume materials, rubber processing chemicals, plasticizers, and chemicals for pesticides and agricultural applications.

The alkali and chlorine industry had the second smallest growth in value of shipments of all the subgroups over the '58-'67 period, only 43 percent. Shipments in 1970 are estimated to be about $832 million, up 65 percent from 1958. Production of chlorine for 1970 is estimated to be 10.6 million short tons, up 6 percent from 1969. This continuing growth in chlorine production is due to a number of important applications including vinyl chloride monomer, other chlorinated hydrocarbons, pesticides, and paper and pulp bleaching. On the other hand, production of soda ash is expected to increase only slightly since increased demand is expected to be met by the natural form.

Growth of the industrial gas industry has been very high with an increase of 113 percent in value of shipments from 1958 to 1967. In 1970 value of shipments are expected to reach $715 million, or a 158 percent increase from 1958 levels. The greatest contributor has been the rapid growth of air separation plants, where annual growth rates for the period 1958-68 of high purity nitrogen were 37 percent, high purity oxygen 22 percent and argon 19 percent. During the same period, the annual growth rate for hydrogen was 15 percent, helium 12 percent, and nitrous oxide 8 percent. Future growth does not appear as bright, however, with overcapacity indicated in some areas. Growth will probably be selective until demand catches up to the available supply.(9)

Cyclic intermediates and crudes saw a 71 percent increase in value of shipments over the 1958-67 period. Total shipments are expected to reach

$2.1 billion in 1970, up a large 125 percent from 1958. This accelerated growth in intermediates is due to rising demand for production of man-made fibers and polystyrene and phenolic resins, as well as ortho-xylene, cyclohxane, para-xylene, phthalic anhydride, aniline, bisphenol A, and urethane resin precursors.(1)(9)

The slowest growing group of basic chemicals are the inorganic pigments. The increase in value of shipments from 1958 to 1967 was only 31 percent. By 1970, value of shipments is expected to reach $725 million, a 74 percent increase from 1958. One of the fastest growing pigments is titanium dioxide which makes up about 50 percent of the industries' sales. However, much of its recent growth has been as a replacement for other pigments, such as lead.(9)

The inorganic chemicals industry has also exhibited a comparatively slow rate of growth over the 1958-67 period, with an average annual rate of about 4 percent, and an overall increase of 54 percent in value of shipments. In recent years, demand has stagnated for a number of major chemicals used for production of fertilizers and for industrial production of sulfuric acid and inorganic compounds containing nitrogen, phosphorous, and potassium. During 1969 many operations were unprofitable, as new plant expansions encountered reduced demand, which caused price reductions, and many obsolete plants and marginal operations were phased out. Value of shipments in 1970 is expected to increase only 4 percent to $4.5 billion, an increase of only 64 percent from 1958.(9)

Although the industrial chemical industry is growing at a fairly rapid pace, there are two areas where very little growth, and in some cases a decrease from 1958 levels, have resulted, namely in total employment and numbers of plants. Total employment over the period increased only 4.5 percent, a very small figure considering the 83 percent increase in value added by manufacture. Three of the subgroups decreased total employment over the period. Miscellaneous inorganic chemicals exhibited a 9.6 percent decrease in total employment. The organic chemical industry increased its employment 23 percent over the period, but value added by manufacture increased 107 percent.

SECTION FOUR: SOLID WASTES OF THE INDUSTRIAL CHEMICAL INDUSTRY

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SECTION FOUR: SOLID WASTES OF THE INDUSTRIAL CHEMICAL INDUSTRY

Industrial chemical plants generate solid wastes with characteristics probably more diverse than in any other industry. The physical properties of the solid wastes range from rock-hard clinkers of irregular shape to free flowing organic tars. They include the normal municipal and commercial type refuse, consisting of cans, bottles, paper, and garbage, in addition to chemical wastes of varying composition and characteristics. These solid wastes arise from all the functions of an industrial plant including administration, maintenance, and manufacture wherein all materials used will leave the plant either as a product, a salvageable material, or a waste.

The flow of materials and eventual solid waste generation for a typical chemical plant is shown in Figure 5. As can be seen from this schematic diagram, the necessasry materials for offices, cafeteria, manufacturing processes, etc., are transported either directly to the appropriate plant area or to a central shipping and receiving area from which they are distributed. Food and cafeteria supplies and coal or other fuel are normally shipped directly to the specific use area, while laboratory supplies are normally sent through shipping and receiving. The materials consumed by the plant operations eventually become part of the product, or are salvaged or wasted.

Two distinct waste categories are evident from the discussion of total plant waste generation; these are wastes generated directly by the manufacturing processes of the plant, or process wastes, and all other wastes, or non-process wastes.

Non-Process Wastes

Non-process wastes are wastes which are not generated directly by a chemical manufacturing process. They can be classified into three categories

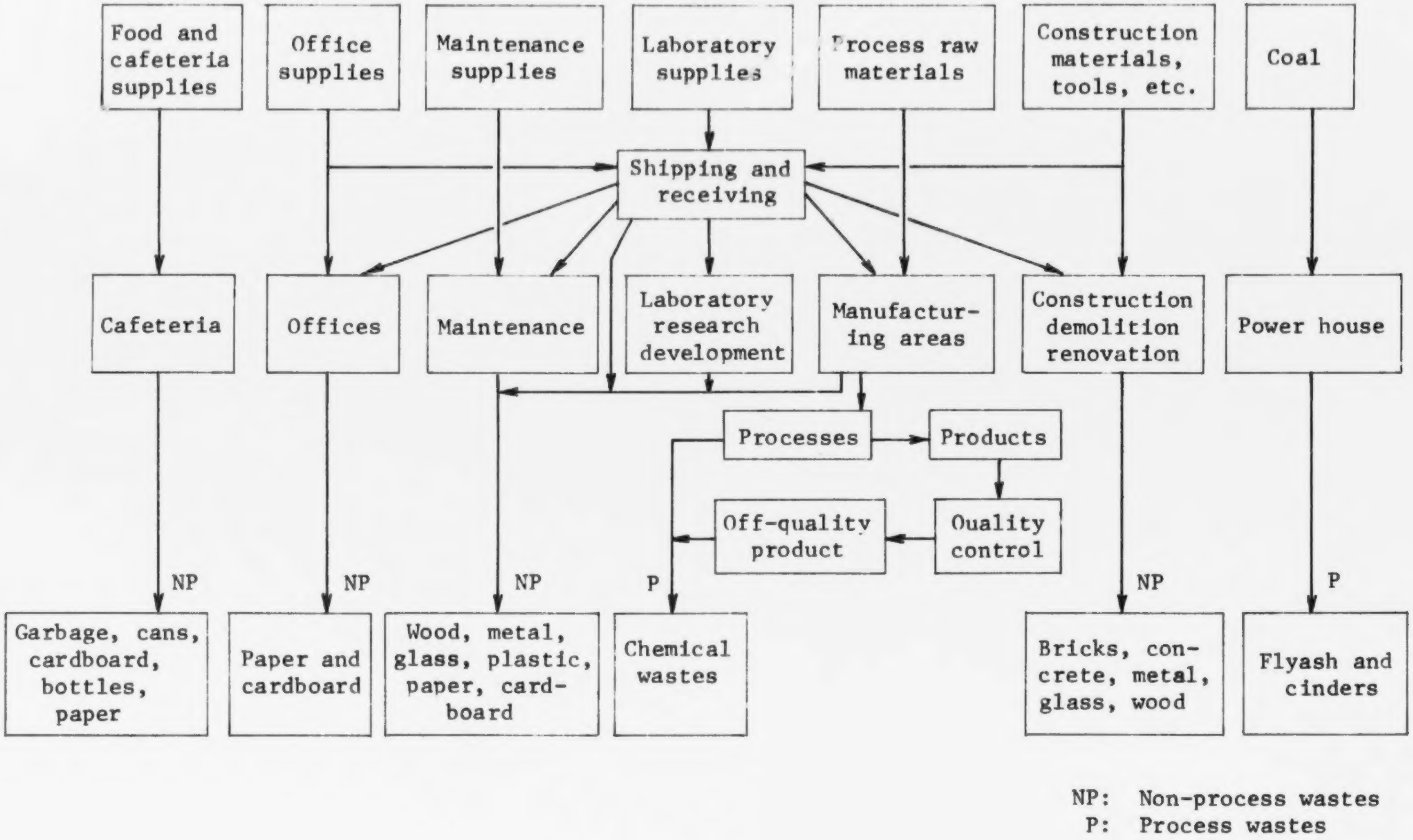
Food and cafeteria supplies
Office supplies
Maintenance supplies
Laboratory supplies
Process raw materials
Construction materials, tools, etc.
Coal
Shipping and receiving
Cafeteria
Offices
Maintenance
Laboratory research development
Manufacturing areas
Construction demolition renovation
Power house
Processes
Products
Off-quality product
Quality control
NP
NP
NP
P
NP
P
Garbage, cans, cardboard, bottles, paper
Paper and cardboard
Wood, metal, glass, plastic, paper, cardboard
Chemical wastes
Bricks, concrete, metal, glass, wood
Flyash and cinders
NP: Non-process wastes
P: Process wastes

Figure 5. Solid waste generation from a typical chemical plant.

related to their disposal characteristics: namely, combustible waste which includes paper, cardboard, wood, and plastic; noncombustible waste which includes glass, brick, concrete, and certain metal wastes such as tin cans; and salvageable metal which includes metallic wastes that can be sold for scrap metal.

Chemical plant combustible waste usually contains a lower percentage of garbage and a higher percentage of dry paper and plastics than municipal refuse, and therefore has a higher heating value. In terms of the Incinerator Institute of America's waste classifications,(34) combustible waste from plants with cafeterias would be type #1 waste, rubbish, and those without a cafeteria would be type #0 waste, trash.* Type #1 waste is defined as consisting of 20 percent garbage and 80 percent rubbish with a heat content of 6500 BTU per lb.; type #0 waste is 100 percent trash and 8500 Btu per lb. as fired.

Non-process solid wastes result from the delivery of the materials necessary to sustain, directly or indirectly, the life of the chemical process. Practically every operating unit within a chemical plant generates non-process waste through obsolescence or use of an auxiliary material. Non-process waste generated by plant operations is specific to a particular operation (Figure 5).

Shipping and receiving operations encounter materials in various kinds of packaging, e.g., cartons, paper bags, cloth sacks, steel drums, fiber drums, etc. Most packaging material cannot be reused and is discarded. Steel drums are an exception since they can often be reconditioned, but they have been replaced for many applications by fiber drums which are seldom reused.

The use of wooden pallets has greatly increased in recent years as a result of improved methods of raw materials handling. The cost of reconditioning pallets is usually prohibitive, and broken pallets are discarded. Pallets in good condition can sometimes be returned to the supplier. Where this is not the case, they must either be used elsewhere in the plant, shipped with outgoing material, or sent to disposal.

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*#1 waste (rubbish): highly combustible waste, paper, wood, cardboard cartons, including up to 10 percent treated papers, plastic or rubber scraps, commercial and industrial sources. #0 waste (trash): combustible waste paper cartons, bags, wood scraps, combustible floor sweepings, domestic and commercial sources.

Other plant operations also carry out the same cycle of use, replacement, and disposal. The cafeteria uses napkins, paper cups and plates, and replaces broken or chipped glasses and dishes. The laboratory replaces broken or cracked glassware, and maintenance personnel replace broken or obsolete equipment. Demolition materials such as bricks and wood which are not economical for further construction are replaced by new materials. All this used and replaced material, if it cannot be salvaged or reconditioned, is wasted.

Process Wastes

Process wastes are wastes generated directly from a chemical process. They are related to the wide variety of industrial chemicals and their manufacturing processes. Just as the chemicals differ widely in character, so are the process wastes from different processes and plants extremely variable in composition and characteristics. Non-process waste composition and characteristics have been reported in detail in a number of publications.(16,22,35,44) Industrial chemical industry non-process waste is quite similar in composition to those reported. Chemical plant process waste is specific to the industrial chemical industry and has received little attention. This lack of information was a reason for the undertaking of this study.

Process Waste Categorization. A number of methods for categorization of process wastes was considered, many quite detailed. The categories chosen for this study were kept general to allow the industry-wide waste inventory to be accomplished within the scope of the program. Specific categories based on waste characteristics or chemical composition would require a very large number of categories and detailed information on each reported waste well beyond the intended scope of this study. In addition, the categories selected had to be expressed in terms familiar to plant personnel to assure a consistent response on the mail questionnaire. Following discussions with chemical plant personnel during initial plant visits, the categories defined in Table 12 were decided upon.

Sludge. Sludge is a broad category including all types of solid wastes except dry powder and granular material. Most filter residues and flyash and some off-quality product are also sludges. Wastes were classified in the more specific categories if possible, and classified as sludge only if they did not fit these other classifications.

Sludges have a variety of physical and chemical characteristics. In terms of moisture content, they can vary from a wet semisolid to a hard cake. Many are wet when first removed from the process, and upon dumping will dry to a hard solid. They can be either organic or inorganic and consist of a chemical mixture such as the impurities in an ore, or they can be relatively pure chemical compounds such as ferrous sulfate crystals or gypsum.

Filter Residue. Filtration is usually applied to remove product solids from a process stream when the solids content is high and the liquid is to be discarded. It is also applied when the solids content is low and high clarity of product liquid is desirable. In the latter case, precoat filters are applicable or filter aid is added to the filter feed.

Filter residues differ widely in physical characteristics but are invariably considered as solid wastes together with a certain quantity of filter membranes, whether they be cloth or paper.

Tars. Tars are associated with production of organic chemicals from

TABLE 12

PROCESS WASTE CATEGORIZATION USED IN THIS STUDY

Sludge:	A soft mud, slush or mire usually resulting from dewatering of slurries without filtration.
Filter residue	Material removed from the process stream by a filtering device (filter cake). It sometimes contains the filter media also.
Tars:	An organic residue of mixed chemical composition usually appearing as a still bottom or distillation residue.
Off-quality product:	A chemical product not meeting the commercial specifications for the particular product and not of sufficient economic worth to warrant further purification or recovery.
Flyash:	The residual solid ash remaining from the combustion of coal, either as furnace bottom ash or that caught by stack emission controls.
Other:	Any chemical waste that does not fit into one of the above categories. Examples here are: spent catalysts; contaminated containers, etc.

coal and oil. There are usually impurities in the feedstock of a process, which are removed as distillation residues or still bottoms. Most organic substances when subjected to a high temperature in the absence of air, undergo simultaneous decomposition to smaller molecules and polymerization to higher molecular weight char or coke with the production of a dark-colored byproduct called tar. The tar may contain many valuable chemicals which can be extracted by refining. When all of the economically important chemicals have been extracted from the tar, the residue is wasted. Waste tars are usually mixtures of high boiling compounds, the composition of which is often unknown. Tars can exist both as a solid or a liquid at room temperature, depending upon their chemical composition. Both solid and liquid forms may be generated through identical means, their chemical compositions may be similar, and they are most often disposed of together, either by incineration or land disposal but rarely into receiving waters. In this study all tars were considered to be solid wastes.

Off-Quality Product. Improper conditions or faulty operation of a process can result in a chemical product that does not meet commercial specifications. In many cases, this means the product contains too great a concentration of impurities or the chemical composition has been altered to the extent that it is undesirable for its intended application. Such a material is commonly called an off-quality product. Sometimes the material can be sold as an inferior grade of the intended product, or recycled back into the process, or separately refined to obtain the original product. Where it is not economical to recover the material, it is wasted. Off-quality product waste can be obtained from practically every chemical process, though infrequently in most cases, since wasting it is highly undesirable and often avoidable. Thus, even some processes which do not generate solid wastes in normal operation may occasionally have to dispose of some off-quality product solid waste. Since off-quality product is obtained from many processes, the chemical and physical characteristics of the waste are highly variable.

Flyash. Flyash was considered to be in the process waste category since it is the result of the combustion of coal to produce heat energy. The heat is usually in the form of steam which is utilized for plant operations. All coals contain a certain percentage of inert material which on combustion is not chemically converted to gaseous products but remains a solid, either as flyash collected in stack control devices or as bottom ash or slag remaining in the boiler. Typical coal ash contents range from 3 to 13 percent by weight. Ordinarily the carbon content of flyash from an industrial powerhouse is much higher than that from a utility. Industry is reluctant to operate its powerhouses at a high efficiency of combustion because of much higher investments required. It is not unusual for the flyash from industry to contain up to 12 percent carbon. In addition to adding to the solids load, the high carbon content prevents the use of the flyash in pozzolanic cement.

Other. In addition to the above waste types, a few wastes were found that did not fall within one of the waste categories and were termed "other" wastes. Included in this group are dry solid chemicals in powder, pellet, and granular form, many of which were spent catalysts in pellet form. Some chemically contaminated containers and similar materials were considered "other" process wastes if they could not be handled with ordinary trash, but had to be disposed of with the process wastes. In addition, certain major items of equipment belonging to a chemical process were included if they were peculiar to the particular process, and were not disposed of with non-process wastes. An example would be the waste concrete cell parts from a chlorine-caustic cell.

Process Waste Generation. Process wastes are not the result of use or replacement but are generated by process operations associated with direct chemical manufacture. The operations are either chemical conversions or unit operations. Chemical conversions are processes where chemical changes occur. The operations within a chemical manufacturing process are the sources of solid wastes associated with the manufacture of a particular chemical.

Chemical conversions and unit operations are not necessarily tied to production of a specific chemical. Frequently, the equipment used to carry out the conversions and operations is used for manufacturing many different chemicals. For example, the equipment for the chemical conversion of nitration consists of a cast-iron reactor called a nitrator. It can be used in the nitration conversion for many chemicals such as nitrobenzene, nitronaphthalene, or TNT. Other examples are the unit operations of filtration and evaporation which are universally used in chemical manufacturing processes.

The solid wastes generated by similar chemical conversions or unit operations are not necessarily produced in the manufacture of all chemicals which utilize these same basic steps. In fact when the same equipment is used to produce a different chemical, no solid waste may be generated at all. Chemical and physical operations many times act together in solid waste generation. Quite frequently, chemical reactions will produce two products, only one of which may be useful. When this happens, the useless reaction product is generally separated by physical means such as filtration or distillation.

Chemical Conversions. There are a great many chemical conversions used in the manufacture of industrial chemicals, some of which may generate solid waste. The chemical conversions are designations for groups of reactions involving similar chemistry, such as: Sulfonation, which is the formation of a sulfonic acid, a compound containing the sulfonic group in its molecular structure,

TABLE 13

PRINCIPAL CHEMICAL CONVERSIONS*

Acylation
Alcoholysis
Alkylation
Amination by reduction
Ammonolysis
Aromatization or cyclization
Calcination
Carboxylation
Causticization
Combustion (uncontrolled oxidation)
Dehydration
Diazotization and coupling
Double decomposition
Electrolysis
Esterification (sulfation)
Fermentation
Friedel-crafts (reactions)
Halogenation
Hydroformylation (oxo)
Hydrogenation and dehydrogenation
Hydrolysis and hydration (saponification, alkali fusion)
Ion exchange
Isomerization
Neutralization
Nitration
Oxidation (controlled)
Polymerization
Pyrolysis or cracking
Reduction
Silicate formation
Sulfonation

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*See Reference #49 for all chemical conversions.

e.g., the conversion of benzene into benzene-sulfonic acid Halogenation, which is the incorporation of one of the halogen elements, usually chlorine or bromine, into a chemical compound, e.g., benzene treated with chlorine to form chlorobenzene and, Hydrolysis, in which water acts upon another substance to form one or more entirely new substances, e.g., the reaction of the ions of a dissolved salt to form various products, such as acids, complex ions, etc. The principal chemical conversions are listed in Table 13.

Solid waste generated by chemical conversions falls into four categories: (a) Solid byproducts which are formed by the process reactions and are not further consumed in the process. (b) Solid catalysts necessary for the reaction, not consumed during the reaction, and that cannot be reused. (c) Any solid impurities in the feed material or other compounds, which are not involved in the reaction. (d) A portion of the feedstock material that did not undergo the reaction and cannot be recycled back into the process. The discussion in Section Five of solid waste generation from the manufacture of specific industrial chemicals includes many examples of solid wastes generated by chemical conversions.

Unit Operations. Whereas chemical conversions change compounds into new chemical entities, unit operations physically extract or separate desired chemicals from parent materials. It is apparent that the common unit operations cover many of the steps found in almost every process (Table 14). These physical operations may comprise an entire chemical manufacturing process or operate in conjunction with a chemical conversion, by preparing the feedstock material before it enters the conversion vessel, separating the products and byproducts produced from the conversion, and purifying the final product. Each of these functions of unit operations may generate solid wastes by removing a solid material from the process stream.

TABLE 14

COMMON UNIT OPERATIONS*

Pumping
Conveying
Packaging
Storing
Grinding
Agglomerization
Compacting
Evaporation
Heat transfer
Precipitation
Condensation
Refrigeration
Distillation
Gas absorption
Solvent extraction
Humidification
Drying
Leaching
Crystallization
Sublimation
Screening
Flotation
Gaseous diffusion
Dialysis
Electrodialysis
Filtration
Mixing
Agitation
Ion exchange
Centrifuging
Thickening
Clarifying
Electrostatic separation

*See Reference #49 for all chemical conversions.

Purification or separation by precipitation, filtration, and distillation generate the largest quantities of solid wastes. These operations may remove wastes formed by chemical conversions from the process stream, or they may remove wastes originally present in the feedstock material as impurities.

Precipitation and Settling. The purification of solutions by the removal of undesirable constituents as insoluble material is a well-known chemical engineering principle. The physical state of the chemical impurity can be changed in several ways, such as by raising or lowering the pH value by acid or alkali addition. When the impurity is present as a suspended solid, the use of coagulants such as aluminum or iron salts may be called for. The resulting solid may be separated from the purified solution by settling, centrifuging or filtration.

The most common means of separating solids from liquid is by sedimentation in tanks or ponds. If the quantity to be removed is relatively small, ponds which can be cleaned occasionally are feasible. Settling ponds are not ordinarily used to purify liquids which are considered chemical products. Ponds are used on water streams which are clarified for process or cooling purposes. In most cases, the stream is the plant effluent, and clarification is practiced to minimize pollution of watercourses.

Distillation and Evaporation. Distillation is used to separate compounds in a liquid mixture by vaporization and condensation. Evaporation is akin to distillation, although it is usually applied to concentrate a liquid by removal of water. Solid wastes can result from either of these unit operations depending on the chemicals involved. Distillation can produce "tars" as still-bottoms, and evaporation can lead to crystallization of an impurity from a concentrated liquid. Examples of tar generation from specific chemical processes are discussed in Section Five.

Other Sources of Process Waste. Significant solid waste quantities are generated by other functions related to chemical processing which are not chemical conversion processes or unit operations.

Power Generation. The solid wastes from the use of coal to produce steam and/or power can be a major consideration, particularly in large chemical plants. These wastes consist of bottom ash or slag and flyash. Flyash is no longer acceptable for discharge into the atmosphere. It is usually removed by electrostatic precipitation or other means, and becomes a solid waste. It is usually collected in a dry state, but is frequently transported hydraulically to a settling pond. Handling economics determine the method used.

Air Pollution Control. The capture of solid particulate matter by air pollution control equipment usually results in solid waste. Solids removal from gas streams can be accomplished by such equipment as baghouses, electrostatic precipitators, single cyclones or multiclones, settling chambers, and various scrubbers. Equipment using a liquid as the collection medium, such as scrubbers and wet cyclones, may send the effluent directly to receiving waters or to waste water treatment where the solids are removed. The solids removed in such devices are usually not economically recoverable and are discarded.

Common applications for control equipment are for grinding, pulverizing, drying, and combustion operations. Some drying and calcining operations, particularly rotary dryers and kilns, can be dusty. Heated air or combustion products passing through the dryer or kiln also picks up dust. At times, product quality control requirements do not permit recycling of the dust to the process, and it is discarded.

Examples of processes emitting air-entrained dust requiring air pollution control are: calcium carbide production in electric furnaces; lime production in vertical and rotary kilns; and various materials handling operations. In the manufacture of calcium carbide, lime and coke are charged to an electric furnace wherein the lime is reduced by coke to calcium carbide and carbon monoxide. A carbide furnace may release as much as 96,000 cubic feet of gas per minute containing approximately 1.0 to 3.0 grains of dust per cubic foot.(4) A high-efficiency collector is necessary to remove the small particles of lime present in the gas. An impingement scrubber is often used for this purpose. The fluid waste from the collector is usually sent to ponds or lagoons where the solids are removed through settling, or is sent first to thickeners, where the thickened sludge is removed and disposed of in large diked areas.

Coke used in the manufacture of calcium carbide must be crushed, sized, and dried. This procedure generates substantial quantities of dust which are controlled by mechanical and bag collectors. Additional dust is generated when the calcium carbide is crushed and sized prior to commercial usage.

Lime kilns also release substantial quantities of dust. Rotary lime kilns have been found to emit as much as 26,000 cubic feet of gas per minute with a dust load of approximately 8 grains per cubic foot. Vertical kilns can emit 33,500 cubic feet of gas per minute with a dust load of 0.9 grains per cubic foot.(4) Total dust quantities can range from 5 to 15 percent by weight of the lime produced for rotary kilns, to about one percent for vertical kilns.(21) Multiple cyclones and wet scrubbing systems have also been used to control dust emissions from this process.

Solid materials collected by air pollution control devices often can be recycled back to the process. An example of partial recyling of materials removed in control devices, although not part of SIC #281, is in a cement kiln where relatively large particles caught in the primary collectors (cyclones) are in essence partially calcined clinker and can be readily returned to the kiln. On the other hand, fine materials reaching the precipitator or baghouse are rich in alkalis (because of the high volatility of sodium and potassium). Such materials must be discarded; excessive amounts of these materials weaken the cement.

Waste Water Treatment. Chemical plants usually have waste water streams from both sanitary facilities and process operations. Normally the two streams are treated and disposed separately, although some plants do have combined treatment. Treatment facilities for this waste water stream may consist of primary and/or secondary treatment.

Primary treatment consists mainly of removing suspended solids from the waste stream. Settling tanks, thickeners, centrifuges, flocculation tanks, ponds or lagoons, are used, depending on the degree of removal required and the type of solids to be removed. The solids settle out to form a sludge commonly called primary sludge.

Secondary water treatment usually involves biological treatment of the waste waters. Waste waters will often contain dissolved organic materials, particularly from chemical plants involved in organic syntheses. Such wastes can contain alcohols, aldehydes, phenols, amino compounds, organic acids, and others. Without secondary treatment, most of these compounds will break down in the receiving waters to simpler organic reaction products through the action of bacteria. In utilizing this organic matter as food, the bacteria consume the oxygen present in the receiving water for their metabolism and growth. If the quantity of organics is great enough, however, the oxygen content can be completely depleted or dropped below levels which can support other aquatic life. Present State and Federal laws prohibit such misuse of receiving streams.

Sometimes the organic matter can be isolated or segregated so that salvage or chemical destruction can be undertaken. In many cases, however, the organic matter reaches the plant's sewer system and is diluted too far for economical recovery. In these instances, biological treatment may be the only practical answer.

If the volume of the waste stream is relatively small, biological treatment by a process known as "extended aeration" can be utilized. This process usually involves facilities for 24-hour aeration, in conjunction with sludge removal and recycling back to the aeration chamber. In this way, the sludge is almost completely depleted so that the effluent carries very little in the way of suspended solids to the receiving waters.

When flows become large, plant size becomes a limiting factor, and a process known as "activated sludge" becomes applicable. This process involves subjecting the wastes, inoculated with sewage bacteria, to a reaction period of about four hours followed by "solids" separation in a clarifier. These "solids" are the result of bacterial growth of the synthesizing of cellular material. They act to absorb the organic matter in solution so that the liquid portion is greatly reduced in its oxygen demand. While the waste water is not completely "pure", the biochemical oxygen demand content is low enough to permit discharge to a receiving waterway.

During the four-hour aeration period, the sludge content of the aerated mixture must be controlled in order to maintain oxidizing conditions; i.e., a certain amount of sludge must be removed for disposal. This is accomplished by passing the effluent from the aeration tank through a clarifier to separate all of the solids by settling. Some of the sludge is sent to waste while the rest is returned to the aeration tank.

The activated sludge is highly absorptive, and a large amount of the organic matter in the original waste is removed with the wasted sludge. The proper disposal of this sludge is the major solid waste problem of the activated sludge process. It will develop odors if piled in the open, and therefore must be buried, burned, or barged to the ocean. Each of these methods can be costly.

An accurate estimate of biological treatment used by the industrial chemical industry has not been made. This survey was too broad to permit this level of detail. It is certain, however, that with stricter enforcement of regulations governing water quality, this method of treatment will expand sharply within the next few years.

The removal of nonbiodegradable materials from waste waters may also generate solid wastes. Such heavy metals as iron, copper, zinc, and cadmium are removed by precipitation with the addition of alkali. Addition of soluble barium salt, such as barium sulfide, is used to precipitate chromium (as chromates). Acidic wastes are normally neutralized with lime and other inexpensive alkali which may precipitate a solid calcium salt. Conversely, sulfuric acid and waste hydrochloric acid are commonly used to neutralize alkaline waste waters which may also precipate salts.

Pilot Plants. Pilot plants are used to evaluate a particular chemical production process before construction of a full-scale units to large tonnage quantity approaching full scale. During the testing procedures, a variety of solid wastes may be generated.

Any waste which is inherent to the basic production process will be generated by the pilot unit. In addition, certain malfunctions in the process may produce undesirable side reactions or other abnormalities which may result in solid wastes. Until the process is operating efficiently, quantities of off-quality product may be produced.

Solid wastes from pilot plants are usually generated in batch rather than in continuous quantities. The pilot plant is normally operated intermittently and disassembled after it has been tested sufficiently and has been either rejected or accepted for full-scale construction. Since the wastes are often generated by new and unproven processes, they may be dissimilar to other process wastes generated by the plant, and as such, may present difficult disposal problems.

Dredging. Dredging is used for the removal of process wastes from ponds and lagoons, to build shipping facilities, and to clear waste water drainage channels.

Many plants are located near ship channels where it is possible to build their own piers for handling tankers or ore barges. While the maintenance of these berths does not bear directly on chemical process wastes, the disposal of the dredged material is the plant responsibility. Such disposal problems usually arise every three or four years but can be an annual problem in some cases.

Some plants utilize open drainage ditches and channels for the flow of waste water through the plant. In some cases, the silt from the bottoms of these channels is removed and used as fill. Neither dredge spoils from construction of shipping facilities nor maintenance of drainage channels was reported on the mail questionnaire, indicating that the plants did not consider the material a solid waste. It should be considered as such, however, since it is associated with the plant's operations and in many cases, presents a difficult disposal problem.

Floor Sweepings. In the course of cleaning around process equipment, chemicals that have leaked or spilled from the equipment are gathered with other dirt. The chemicals are contaminated and discarded. Often the spillage is mixed with saw dust, diatomaceous earth, or similar material to facilitate cleaning which further increases its bulk.

Equipment Cleanout. Periodically, process equipment such as bucket elevators, belts, pipe lines, and tanks, along with storage tanks and tank trucks, are cleaned. The accumulated solids in this equipment are usually treated as solid wastes for disposal.

Parameters Which Influence Solid Waste Generation

The quantity of solid waste generated by a particular chemical production process is influenced by a number of parameters related to process raw materials and operations. Four general parameters repeatedly reported by industry personnel as influencing solid waste generation were: total production, purity of raw materials, efficiency of reaction, and general maintenance of process control. The first parameter, total production, generally applies to almost all processes since solid waste generation is proportional to production volume.

The purity of process raw materials directly affects solid waste generation where the impurities leave the process as solid waste. The effect on waste quantities is proportional to the percentage of impurities.

The efficiency of reactions associated with chemical processes also directly affects the quantity of solid waste generated. In many cases, chemical reactions are stopped before they reach equilibrium or completion, and if the unreacted material remaining cannot be recycled, it frequently appears as a solid waste. Undesirable side reactions can affect the efficiency of the main reaction, and also produce solid compounds requiring disposal.

General maintenance and attention to process operation on the part of operators exhibits a significant effect on solid waste generation. Off-quality product waste is a direct result of process malfunction or carelessness which can usually be avoided through proper process control. It was pointed out by process engineers during our investigation that there are many processes where improper attention either to maintenance or direct controls will result in solid wastes.

For many production processes, the influencing parameters can be related quantitatively to solid waste generation. The relationships are only valid, however, for the particular chemical processes for which they are developed. Since this study grouped all solid wastes into general waste categories, meaningful quantitative relationships could not be formulated for these categories due to the variety of production processes generating each waste type.

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SECTION FIVE: INDUSTRIAL CHEMICALS GENERATING SOLID WASTES

Solid waste generation from general chemical processes was analyzed in detail. In most cases, the process involved the manufacture of a major chemical wherein significant solid wastes were generated. The information on the processes was obtained from the plant visits and from generalized flow diagrams contained in the literature.

It was beyond the scope of this study to attempt to identify the solid waste potential of every chemical production process and to identify each waste. Indeed, this would be a monumental task, for there are over a million different chemicals with almost as many waste products. Such a study would require lengthy and detailed waste surveys at plants manufacturing these chemicals, to which the industry would have to donate substantial amounts of time in a chemical by chemical analysis of waste generation. Also, the industry is changing so rapidly that this detailed a survey would never be truly finalized. Since the need to provide an overall view of solid waste generation, indicating in relative terms those chemical production areas of high waste generation and those where no solid waste is produced. General waste categories were used, based on physical characteristics and sources, thus eliminating the need for chemical identification of the waste which is unknown in many cases.

The following sections discuss the nature of manufacture in each four digit SIC category, including products produced and raw materials used, and the types and quantities of solid wastes generated. A number of specific processes are presented as examples for the industry. The background information on chemical manufacture for each SIC category will be elementary to those active in the industry, but for those interested in industrial solid wastes who are unfamiliar with chemical industry manufacturing practice, the information

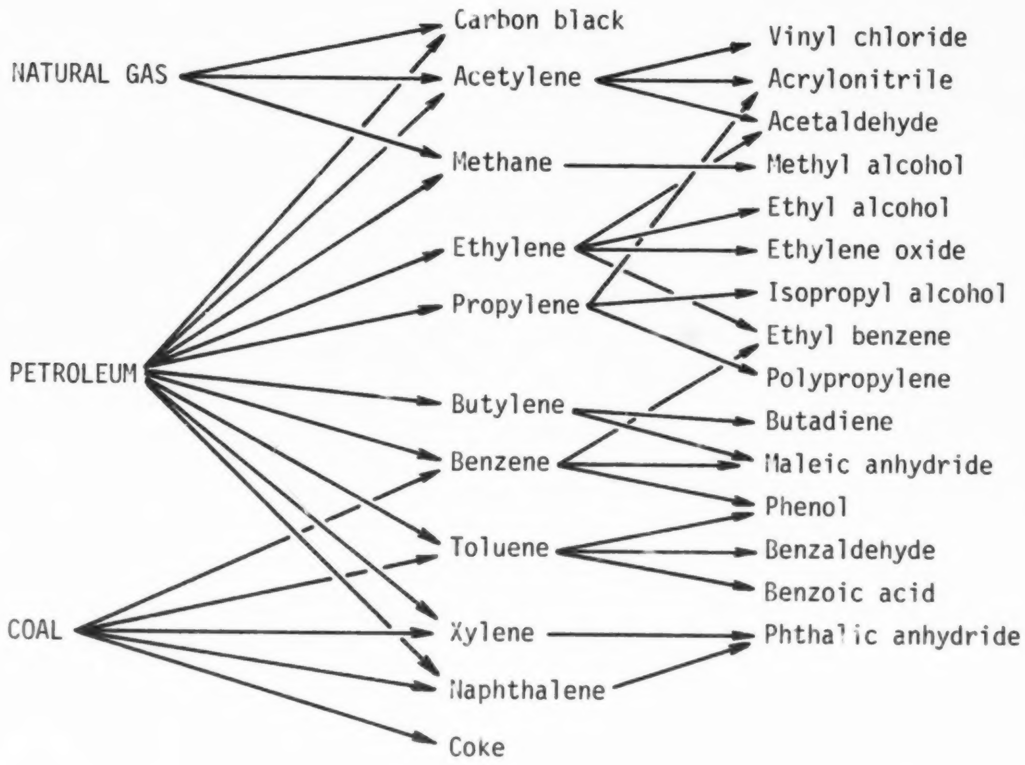
Carbon black
NATURAL GAS
Acetylene
Methane
Ethylene
Propylene
PETROLEUM
Butylene
Benzene
Toluene
COAL
Xylene
Naphthalene
Coke
Vinyl chloride
Acrylonitrile
Acetaldehyde
Methyl alcohol
Ethyl alcohol
Ethylene oxide
Isopropyl alcohol
Ethyl benzene
Polypropylene
Butadiene
Maleic anhydride
Phenol
Benzaldehyde
Benzoic acid
Phthalic anhydride

Figure 6. Interrelationship of chemicals from natural gas, petroleum cuts, and coal. (From Reference #58)

is essential to an understanding of the nature and origins of the wastes.

Organic Chemicals

Major raw materials for the production of organic chemicals are the fossil fuels: coal, petroleum, and natural gas. Many of the same basic chemicals are derived from more than one of these fuels. The interrelationship of chemicals from each of the three raw materials is shown in Figure 6. Competition exists among the raw materials, with petroleum-based chemicals substantially replacing coal-derived chemicals in recent years.

The important classes of synthetic organic chemicals along with their 1967 value of shipments are shown in Table 15.

Coal Chemicals. The basic raw materials for the production of coal chemicals are derived chiefly as byproducts from the production of coke, which is consumed primarily in the steel industry. These raw materials, therefore, depend on the demand for steel. Coke is produced through the destructive distillation of coal; it is thermally pyrolyzed by heating in the absence of air, and is converted into solid, liquid, and gaseous products. The principal product by weight is the remaining solid, coke; the other products are water, tar, crude light oil, gas, and gas liquor. These are the raw materials for the production of coal chemicals, which are the principal chemicals used as the basis for manufacture of countless other organic chemicals. These chemicals and their sources are listed in Table 16.

Statistics for production of the major tar crudes from coal are shown in Table 17, along with production of the same chemicals by petroleum companies. The table shows that in 1967, the bulk benzene, toluene, and xylene was produced by petroleum operators, whereas, as recently as 1953, coal was the leading precursor for benzene. Also, production of many other tar crudes has decreased

TABLE 15

VALUE OF SHIPMENTS OF ORGANIC CHEMICALS
(1967)*

Product code	Chemical group	Total shipments including interplant transfers (millions of dollars)
2815	Cyclic intermediates and crudes	1,650
28151	Cyclic intermediates	1,070
28152	Synthetic organic dyes	325
28153	Synthetic organic pigments, lakes, and toners	162
28155	Cyclic (coal tar) crudes	88
28150	Cyclic intermediates and crudes, n.s.k.	13
2818	Industrial organic chemicals, n.e.c.	5,540
28181	Miscellaneous cyclic chemical products	315
28182	Miscellaneous acyclic chemicals and chemical products	4,050
28183	Synthetic organic chemicals, n.e.c.	586
28184	Pesticides and other organic chemicals (not formulations)	308
28185	Ethyl alcohol and other industrial organic chemicals, n.e.c.	239
28180	Industrial organic chemicals, n.e.c., n.s.k.	39

n.e.c. - not elsewhere classified   n.s.k. - not specified by kind

*From Reference #68.

TABLE 16

PRINCIPAL COAL CHEMICALS*

From Gas	From Gas Liquor	From Light Oils	From Tar	From Coke
Carbon monoxide	Pyridine tar bases	Carbon disulfide	Carbolic oil	Water gas
Hydrogen sulfide	Ammonia liquor	Cyclopentadiene	Phenols	Methyl alcohol
Hydrogen cyanide	Ammonium sulfate	Benzene	Cresols	Ammonia
Hydrogen		Xylene	Xylenols	Graphite
Ammonia		Pyridine tar bases	Naphthalene	Calcium carbide
Nitrogen		Crude naphthas	Creosote oil	Calcium cyanamid
		Toluene	Anthracene	
			Refined tar	
			Pitch	

TABLE 17

U.S. PRODUCTION OF TAR CRUDES, 1953 AND 1967*

Product	Unit of quantity	Production 1967	Production 1953
Crude light oil: Coke-oven operators	1,000 gal	252,000	304,000
Intermediate light oil: Coke-oven operators	1,000 gal	5,560	1,060
Light oil distillates:			
Benzene, specification and industrial grades, total	1,000 gal	969,000	273,000
Coke-oven operators	1,000 gal	90,600	178,000
Petroleum operators	1,000 gal	879,000	63,000
Toluene, all grades, total**	1,000 gal	644,000	156,000
Coke-oven operators	1,000 gal	19,400	36,000
Petroleum operators	1,000 gal	624,000	115,000
Xylene, all grades, total**	1,000 gal	455,000	113,000
Coke-oven operators	1,000 gal	5,490	9,930
Petroleum operators	1,000 gal	449,000	103,000
Solvent naphtha:			
Coke-oven operators	1,000 gal	3,630	6,280
All other light oil distillates, total	1,000 gal	10,700	14,700
Coke-oven operators	1,000 gal	8,400	6,100
Tar distillers***	1,000 gal	2,280	8,560
Naphthalene, crude (tar distillers and coke-oven operators), total****	1,000 lb	521,000	276,000

*From Reference #71.

**Includes data for material produced for use in blending motor fuels.

***Includes solvent naphtha and rubber-reclaiming oils.

****Statistics represent combined data for the commercial grades of naphthalene.

Because of conversion of naphthalene from one grade to another, the figures may include some duplication.

since 1953. Other miscellaneous coal tar chemicals, such as dyes, intermediates, medicinals, flavors, perfumes, resins, rubber chemicals, and many more are also increasingly being taken over by petroleum-based chemicals.

Petrochemicals. Petrochemicals are basic chemicals derived from the raw materials petroleum and natural gas. It has been estimated that more than 80 percent of the organic chemicals of the entire chemical industry are based on petrochemicals, with nearly 10 percent of the sulfur and most of the carbon derived from natural gas or petroleum products. The basic raw materials for petrochemicals supplied by petroleum refineries or natural gas companies are liquid petroleum gas (LPG), natural gas, gas from cracking processes, liquid distillate, and distillates from special cracking processes, as well as cyclic fractions for aromatics. These raw materials are separated from petroleum, usually within the petroleum refinery, by a wide range of physical processes. The raw materials are then chemically converted into the reactive precursors used in the manufacture of various industrial chemicals. Nearly all the petrochemicals are produced through reactions involving many chemical conversions. Most often, these chemical reactions are involved and completed, developed through the research and development efforts of the individual chemical companies.

The major organic raw materials obtained from petroleum and natural gas for the manufacture of petrochmicals are listed in Table 18, along with their associated basic chemicals, intermediates, and final finished products. This listing represents only a small portion of the great number of organic chemical intermediates and products produced from petrochemicals.

Total production of crude products from petroleum and natural gas for chemical conversion was 54.4 billion pounds in 1967, representing $858 million in sales as shown in Table 19.

TABLE 18

RAW MATERIALS AND BASIC PETROCHEMICALS PRODUCED FROM PETROLEUM AND NATURAL GAS*

Raw materials by distillation	Basic chemicals by conversion	Intermediates by conversion	Finished products by conversion
Paraffins and cyclics	Olefins, diolefins acetylene, aromatics	Various inorganics and organics	Inorganics and organics
Natural gas			Carbon black
Sulfides	Hydrogen sulfide	Sulfur	Sulfuric acid
Hydrogen		Synthesis gas	Ammonia
Methane			Methanol
			Formaldehyde
Refinery gases	Acetylene	Acetic acid	Acetates
	Isobutene	Acetic anhydride	Fibers
Ethane**	Ethylene	Isoprene	Rubber
Propane**	Propylene	Ethylene oxide, etc.	Rubber and fiber
n-Butane**	n-Butenes	Butadiene	Rubber
Hexane			
Heptanes			
Refinery naphthas			
Naphthenes	Cyclopentadiene	Adipic acid	Fibers
Benzene		Ethybenzene	Styrene
		Styrene	Rubber
		Cumene	Phenol acetone
		Alkylbenzene	
		Cyclohexane	
Toluene	Toluene	Phenol	Plastics
		Benzoic acid	
Xylenes	o-m,p-xylene	Phthalic anhydride	Plastics
Methyl naphthanes	Naphthalene	Phthalic anhydride	Plastics

*From Reference #58.

**From LPG and refinery cracked gas. Note: Aromatics are also obtained by chemical conversions (demethylation, etc.).

TABLE 19
PRODUCTION AND SALES OF CRUDE PRODUCTS FROM PETROLEUM AND NATURAL GAS FOR CHEMICAL CONVERSION, 1967*

Product	Production (in 1,000 pounds)	Sales (in $1,000)
Grand total.......	54,438,000	858,000
AROMATICS and NAPHTHENES**		
Total	55,000	267,000
Benzene (1° and 2°) total.....	6,485,000	114,000
Naphthalene, all grades.......	377,000	13,800
Naphthenic acids, total.......	24,000	1,300
Toluene, all grades, total....	4,540,000	68,200
Xylenes, mixed, total.........	3,240,000	48,600
All other aromatics and naphthenes***	1,790,000	20,300
ALIPHATIC HYDROCARBONS		
Total...........	54,383,000	591,000
C-7 Hydrocarbons, total......	13,841,000	-------
Acetylene****...............	429,000	-------
Ethane	1,557,000	7,000
Ethylene	11,854,000	133,000
C-3 Hydrocarbons, total......	10,513,000	115,000
C-4 Hydrocarbons, total......	8,226,000	232,000
C-5 Hydrocarbons, total......	784,000	6,200
All other aliphatic hydrocarbons and derivatives, total....	4,618,000	98,600

*From Reference #71.

**The chemical raw materials designated as aromatics are, in some cases, identical with those obtained from the distillation of coal tar; however, the statistics given in the table above relate only to such materials as are derived from petroleum and natural gas. Statistics on aromatic chemicals from all sources are given in Table 3 of the Preliminary Report, "Tar and Tar Crudes, 1967", U.S. Tariff Commission.

***Includes data for 90 percent benzene, crude cresylic acid, crude sodium carbolate and phenate, alkyl aromatics, distillates, solvents, and miscellaneous cyclic hydrocarbons.

****Production figures on acetylene from calcium carbide for chemical synthesis are collected by the U.S. Bureau of the Census.

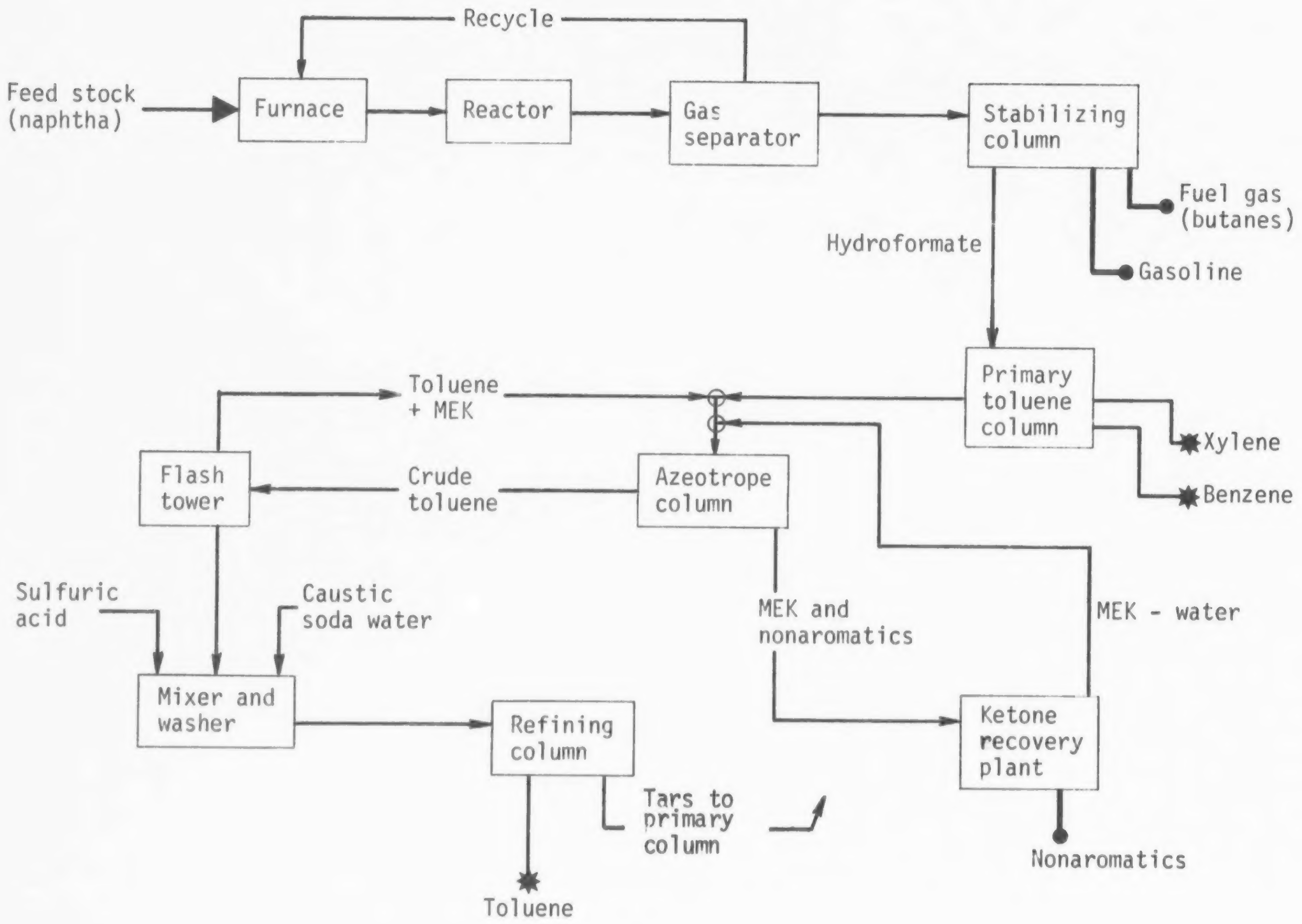
Recycle
Feed stock
(naphtha)
Furnace
Reactor
Gas
separator
Stabilizing
column
Fuel gas
(butanes)
Gasoline
Hydroformate
Primary
toluene
column
Xylene
Benzene
Toluene
+ MEK
Flash
tower
Crude
toluene
Azeotrope
column
Sulfuric
acid
Caustic
soda water
MEK and
nonaromatics
MEK - water
Mixer and
washer
Refining
column
Ketone
recovery
plant
Tars to
primary
column
Nonaromatics
Toluene

Figure 7. Schematic diagram for manufacture of toluene, benzene, and xylene from petroleum by hydroforming. (From Reference #58)

Solid Waste Generation. The organic chemical industry is divided into two SIC categories: 2815: cyclic intermediates, dyes, organic pigments (lakes and toners), and cyclic crudes; and 2818: organic chemicals, not elsewhere classified. The four process waste categories directly associated with chemical processing (sludges, tars, filters residues, and off-quality product) are generated by organic chemical manufacture.

Toluene, Benzene, Xylene. Two organic raw materials, coal and oil, are important to solid waste generation only in that they are used directly to produce the primary organic chemicals as shown in Figure 6. In most cases, the production of the primary organic chemicals from petroleum results in little or no solid wastes as they are produced mainly during the refinery process, whereas coal chemical production does generate significant solid waste quantities. For example, toluene, benzene, and xylene can be produced by catalytic reforming (hydroforming) of petroleum or by fractional distillation of coal tar light oil. The two processes are shown in Figures 7 and 8.

The hydroforming process shows no significant sources of solid wastes. During the process, various other products and byproducts are produced such as gasoline, fuel gas, and nonaromatics, all of which can be used or recycled (such as the gases from the gas separator and tars from the refining column) back into the process.

The process using coal light oil generates sludges and tars as wastes. In this process, light oil from coal carbonization gases containing the crude products are refined by distillation and washing with sulfuric acid. The procedures vary from plant to plant, but the normal processing steps are shown on Figure 8. First the crude benzene, toluene, and naphthas are separated from the light oil by a vacuum still. This oil contains the crude products and is

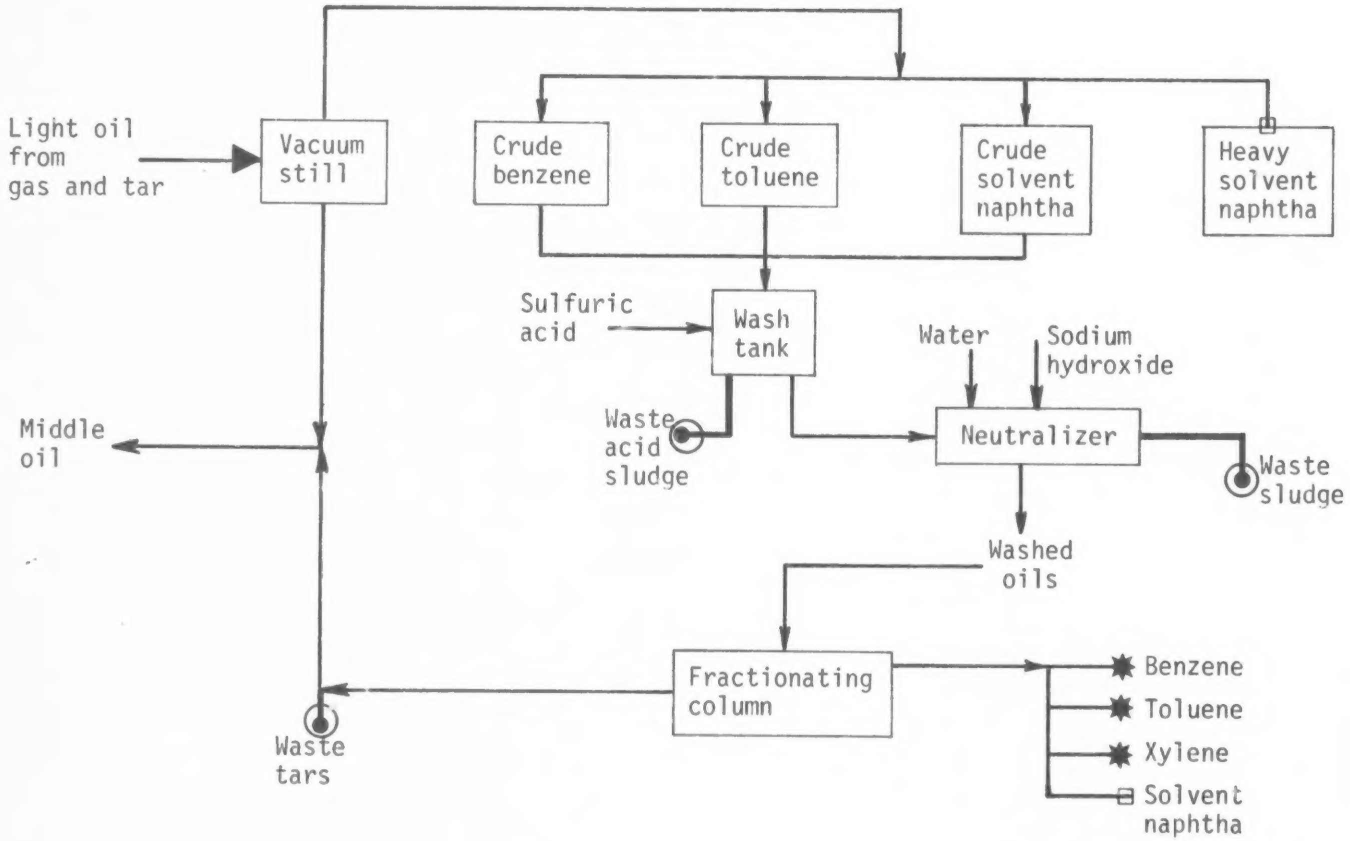
Light oil
from
gas and tar
Vacuum still
Crude benzene
Crude toluene
Crude solvent naphtha
Heavy solvent naphtha
Sulfuric acid
Wash tank
Waste acid sludge
Water
Sodium hydroxide
Neutralizer
Waste sludge
Middle oil
Washed oils
Fractionating column
Waste tars
Benzene
Toluene
Xylene
Solvent naphtha

Figure 8. Schematic diagram for manufacture of toluene, benzene, and xylene from coal gas and tar light oil by acid washing. (From Reference #26)

washed to remove the sulfur compounds, nitrogen bases, and unsaturated compounds. The oil is first washed with sulfuric acid to dehydrate it. It is then washed one or more times with larger quantities of acid, which result in a thick, black, acid sludge which is drawn off and sent to disposal or recovery operations. The oil is then neutralized with a sodium hydroxide solution, again resulting in a sludge. Loss of light oil during washing has been reported as 4 to 6 percent by volume. The acid-washed oil is distilled into benzene, toluene, xylene, and solvent naphtha. Part of the distillation residue is reclaimed as middle oil, and the other portion is disposed of as waste tars.

Benzene, toluene, and xylene are three of the most important and basic organic chemicals from which many chemicals are produced. In some cases, they generate significant quantities of solid wastes.

Phenol. Phenol is one of the most important aromatic chemicals, and is synthesized from benzene or toluene. Phenolic resins consume 50 percent of phenol production. About 30 percent of the remainder is used for production of caprolactam, which is used in the manufacture of synthetic fibers (expecially nylon 6) and plastics, and in bisphenol A, used in the manufacture of epoxy and polycarbonate resins. In 1967 total synthetic phenol demand was 1,300 million pounds. This figure is expected to reach 1,800 million pounds by 1970.(46)

Phenol does occur naturally in coal tar, but extraction from this source is declining in importance. There are six major processes used for the production of synthetic phenol, all of which generate high boiling waste tars or substantial quantities of byproducts or both. The major process in use is the cumene peroxidation process developed by Hercules which produced 56 percent of the phenol in 1967. In this process, cumene obtained from benzene is oxidized to form phenol and acetone, a readily salable byproduct.

The chlorobenzene (caustic) process converts benzene into the sulfonic

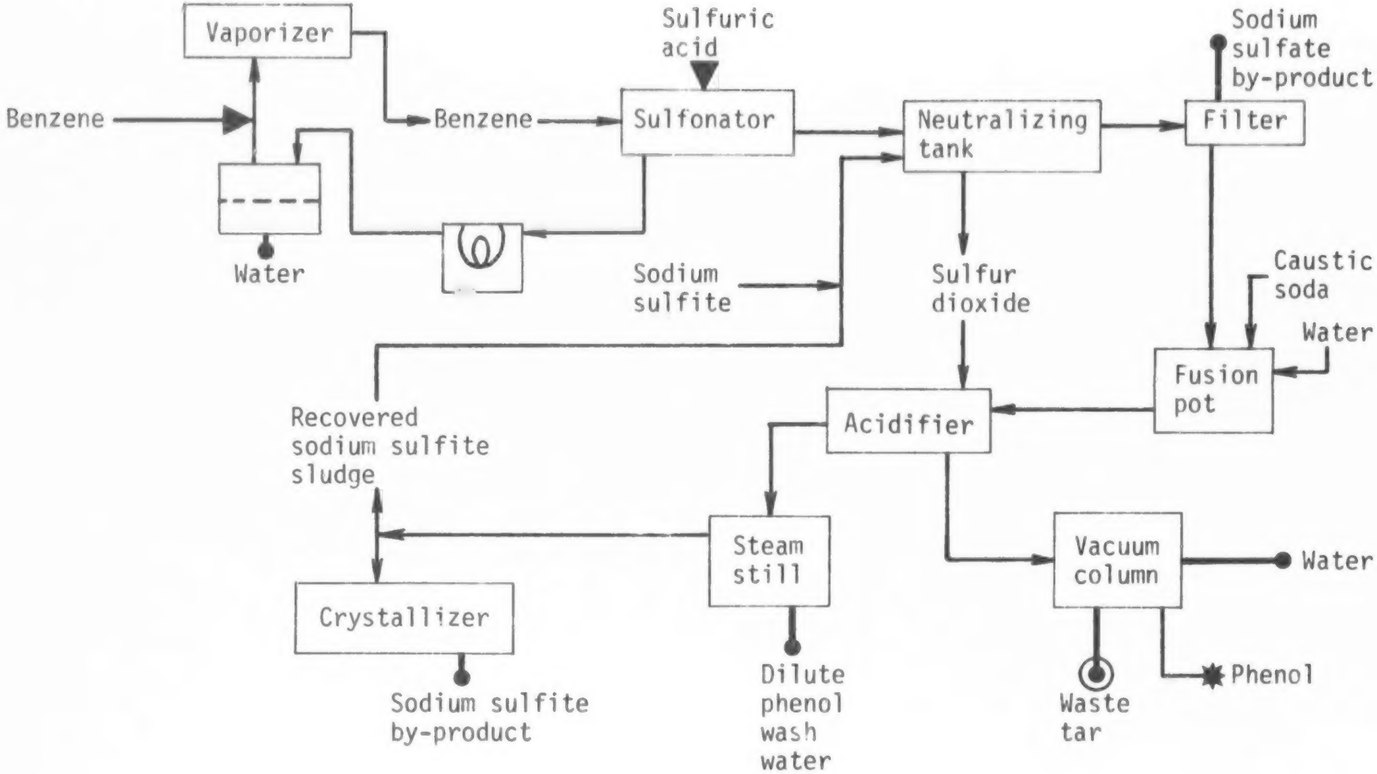
Benzene
Vaporizer
Water
Benzene
Sulfuric
acid
Sulfonator
Neutralizing
tank
Sodium
sulfate
by-product
Filter
Sodium
sulfite
Sulfur
dioxide
Caustic
soda
Water
Fusion
pot
Recovered
sodium sulfite
sludge
Acidifier
Steam
still
Vacuum
column
Water
Crystallizer
Sodium sulfite
by-product
Dilute
phenol
wash
water
Waste
tar
Phenol

Figure 9. Schematic diagram for manufacture of phenol by the benzenesulfonate process. (From Reference #26)

acid and fuses the latter with caustic soda. The sulfonate is treated with acid, liberating phenol which is then distilled off. The last distillation column yields a residue of diphenyloxide which was a waste when the process was first instituted. Today, however, a market has been developed and all can be sold.

In the benzene sulfonate process shown in Figure 9, benzenesulfonic acid is prepared in a sulfonator by the action of concentrated sulfuric acid on benzene. After sulfonation, the product is added rapidly to a neutralizing tank containing a solution of sodium sulfite or sodium carbonate. The neutralization tank yields sodium sulfate (which precipitates out and is filtered from the solution) and sodium benzenesulfonate liquor which is pumped to a fusion pot. The pot, charged with fused caustic soda, yields sodium phenate, sodium hydroxide, and sodium sulfate in solution. The solution is acidified with sulfur dioxide, liberating phenol as an upper layer over an aqueous solution of sodium sulfite and sodium sulfate. The phenol is refined by distillation, yielding a waste tar consisting of impurities. The sodium sulfite and sodium sulfate are byproducts which can usually be sold.

The regenerative (Raschig) process produces phenol from benzene and hydrogen chloride. Like the benzenesulfonate process, a waste tar consisting of high boiling materials is generated from the final refining column.

In a recent process developed by Dow Chemical Co. shown in Figure 10, toluene is used as the starting material. This process is said to yield a minimum of byproducts and waste materials. The process operates through oxidation of toluene to benzoic acid, its conversion over copper catalyst to phenylbenzoate, and hydrolysis to phenol. What waste tar the process does produce is generated from an extractor. The extractor is used to purge the unwanted tars and recover chemical and steam values from the reaction mass which is periodically withdrawn

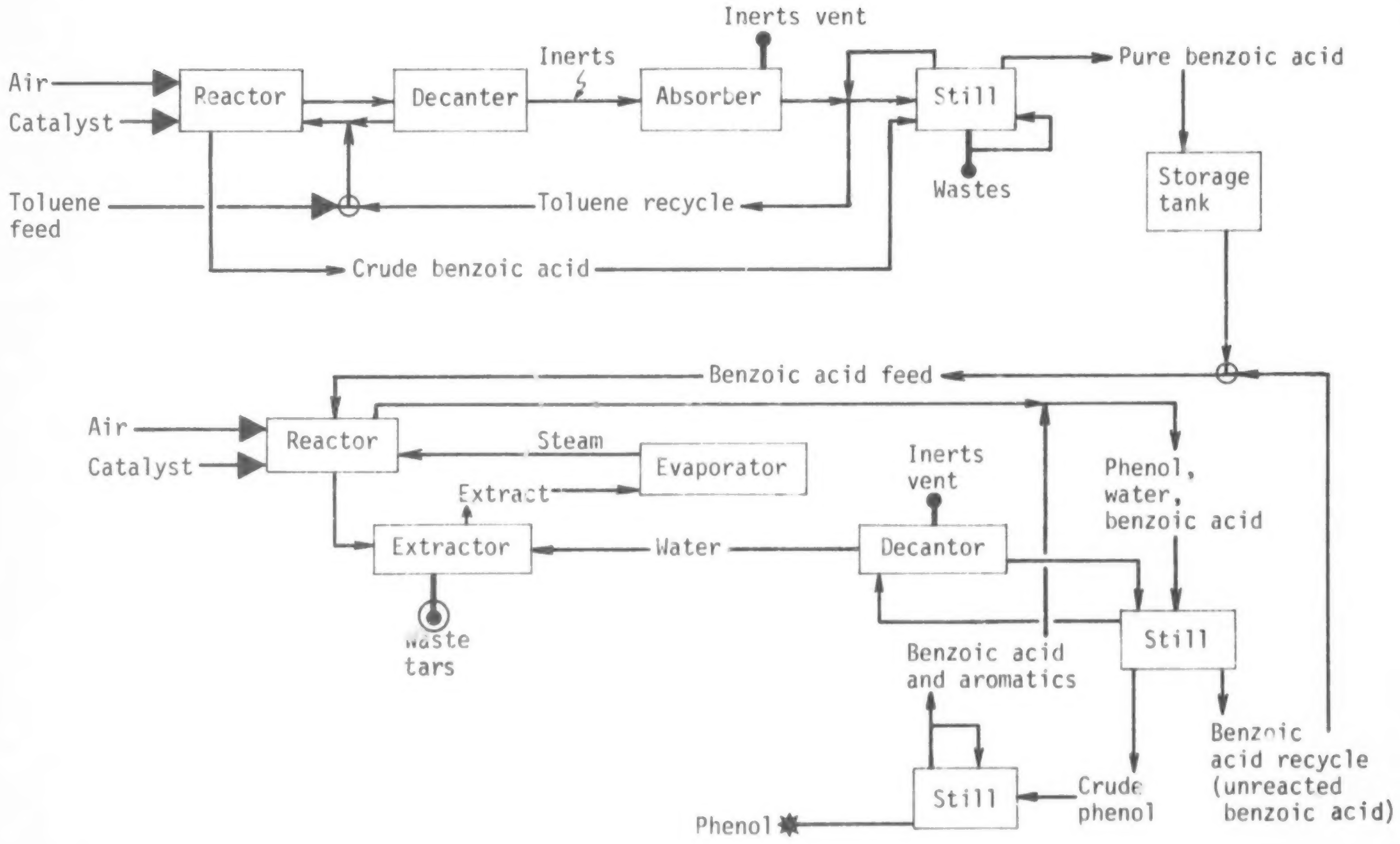
Inerts vent
Air
Catalyst
Reactor
Decanter
Inerts
Absorber
Still
Pure benzoic acid
Wastes
Storage tank
Toluene feed
Toluene recycle
Crude benzoic acid
Benzoic acid feed
Air
Catalyst
Reactor
Steam
Evaporator
Extract
Extractor
Water
Waste tars
Inerts vent
Decantor
Phenol, water, benzoic acid
Still
Benzoic acid and aromatics
Benzoic acid recycle (unreacted benzoic acid)
Crude phenol
Still
Phenol

Figure 10. Schematic diagram for manufacture of phenol from toluene. (From Reference #48)

from the reactor.

Phthalic Anhydride. Phthalic anhydride is a derivative of xylene and its production is a significant waste generator. It may be produced from air oxidation of ortho-xylene as shown in Figure 11. A mixture of vaporized ortho-xylene and preheated air is fed into a reactor, where under the influence of vanadium pentoxide, a catalyst, the main reaction takes place as follows:

ortho-xylene + oxygen = phthalic anhydride + water

The reactor gases containing the phthalic anhydride are cooled, crystallized, and remelted to form the crude product, which is approximately 99 percent phthalic anhydride. The residual impurities are removed in a column under vacuum. The residue is a waste tar which is a brittle solid at room temperature.

Another major process for production of phthalic anhydride uses naphthalene as the feed stock in a very similar process. Again a brittle tar waste is generated at the final purification columns. This process using napththalene accounted for just over 50 percent of the total production of 727 million pounds in 1967.(71) Plasticizers and resins are the major uses for this chemical.

Nitrobenzene. Nitrobenzene is derived directly from benzene. It is primarily used for the production of aniline which consumes 90 percent of its production; the remainder is used for benzidine and solvent dinitrobenzene manufacture. In 1967, 347 million pounds of nitrobenzene were produced with a 5 percent per year growth rate predicted through 1972.(46,71)

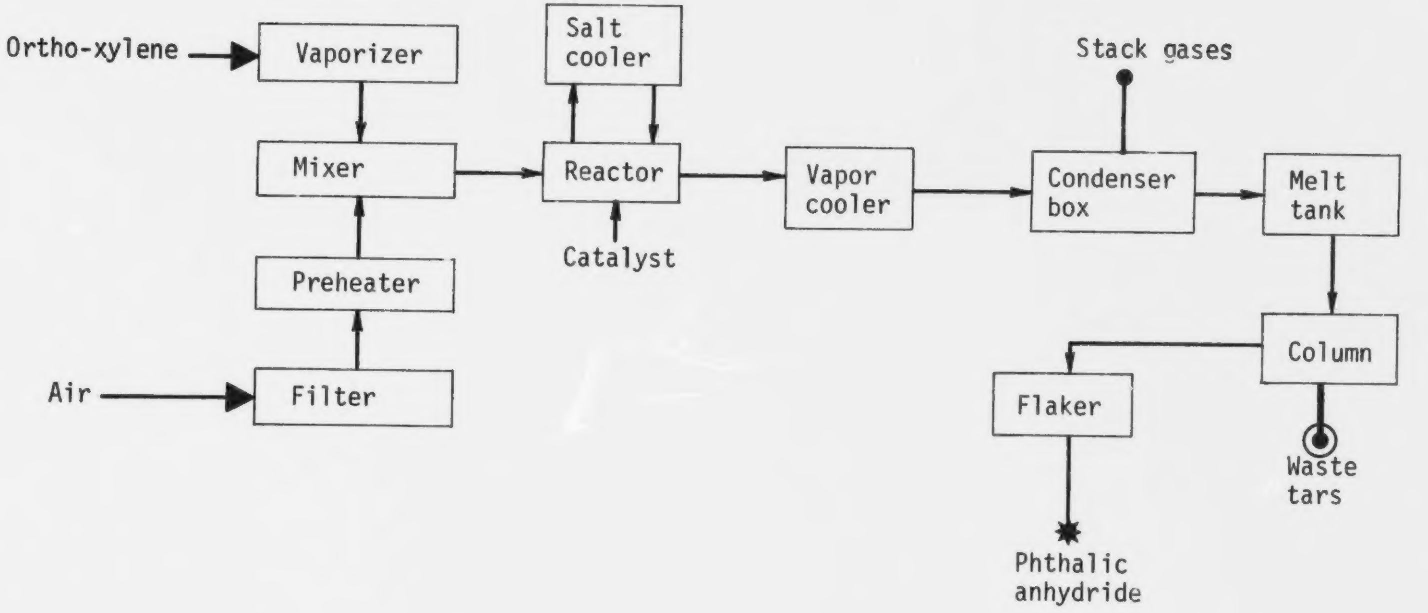
Ortho-xylene
Vaporizer
Mixer
Preheater
Filter
Air
Salt cooler
Reactor
Catalyst
Vapor cooler
Stack gases
Condenser box
Melt tank
Column
Waste tars
Flaker
Phthalic anhydride

Figure 11. Schematic diagram for manufacture of phthalic anhydride from ortho-xylene. (From Reference #26)

The production process as shown in Figure 12 utilizes a nitric acid-sulfuric acid mixture to nitrate benzene. Crude nitrobenzene is separated from the spent acid, washed with dilute sodium carbonate, and refined in a distillation column. The residue from this final distillation process is a waste tar. Crude nitrobenzene is extracted from the process before refining for use in aniline production.

Aniline. Aniline is one of the most important organic bases. It is a poisonous oily liquid, 65 percent of which is used in the manufacture of rubber chemicals and 25 percent in dyes, intermediates, and drug and pharmaceutical production. In 1967, production was 112,778 short tons, and growth is predicted at 6 percent per year through 1973.(46,71)

Production of aniline generates waste tars from the final distillation process for recovery of the chemical that are similar to those of nitrobenzene production. The process using crude nitrobenzene shown in Figure 13 operates through reduction of the nitrobenzene with iron filings or borings with 30 percent hydrochloric acid as a catalyst. Crude nitrobenzene, iron borings, and hydrocholoric acid are fed to a reactor where the main reaction takes place

nitrobenzene + iron + water = aniline + ferric oxide

The ferric oxide comes out of the reactor as a sludge for disposal or possible recovery. The sludge is sometimes sold to steel mills for use as a substitute for iron ore. In the final distillation column, a residual waste tar is generated and discarded.

Isocyanates. Isocyanate production generates tar wastes as the result of polymerization and distillation. The organic isocyanates are compounds in which the isocyanate group, NCO, is attached to an organic radical. They react readily with a great variety of organic compounds and may also react with

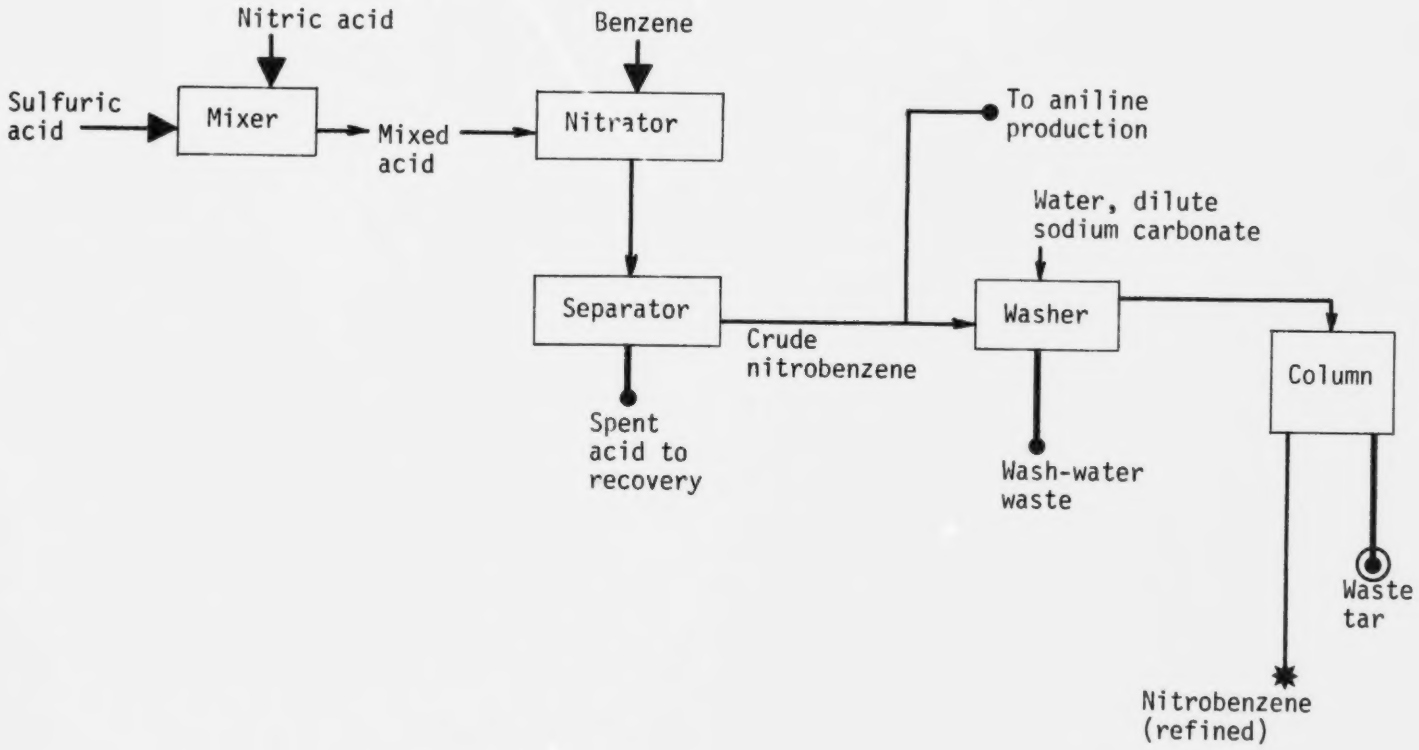
Nitric acid
Benzene
Sulfuric acid
Mixer
Mixed acid
Nitrator
To aniline production
Water, dilute sodium carbonate
Separator
Washer
Crude nitrobenzene
Column
Spent acid to recovery
Wash-water waste
Waste tar
Nitrobenzene (refined)

Figure 12. Schematic diagram for manufacture of nitrobenzene from benzene and nitric acid. (From Reference #26)

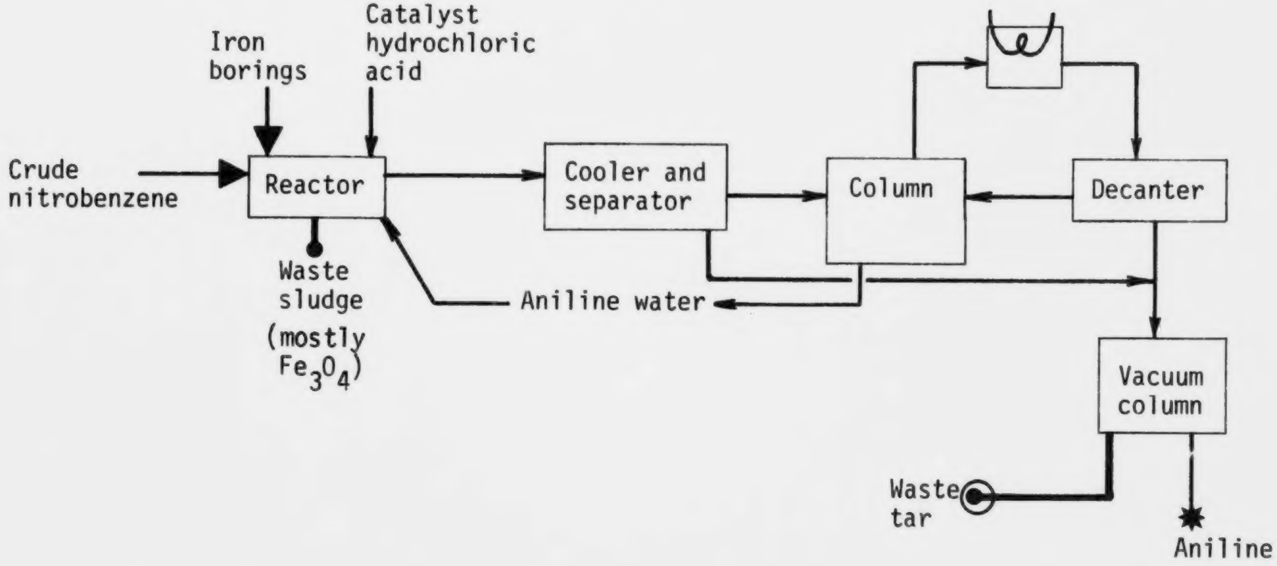
Crude nitrobenzene
Iron borings
Catalyst hydrochloric acid
Reactor
Waste sludge (mostly Fe_3O_4)
Cooler and separator
Aniline water
Column
Decanter
Vacuum column
Waste tar
Aniline

Figure 13. Schematic diagram for manufacture of aniline from nitrobenzene by reduction. (From Reference #26)

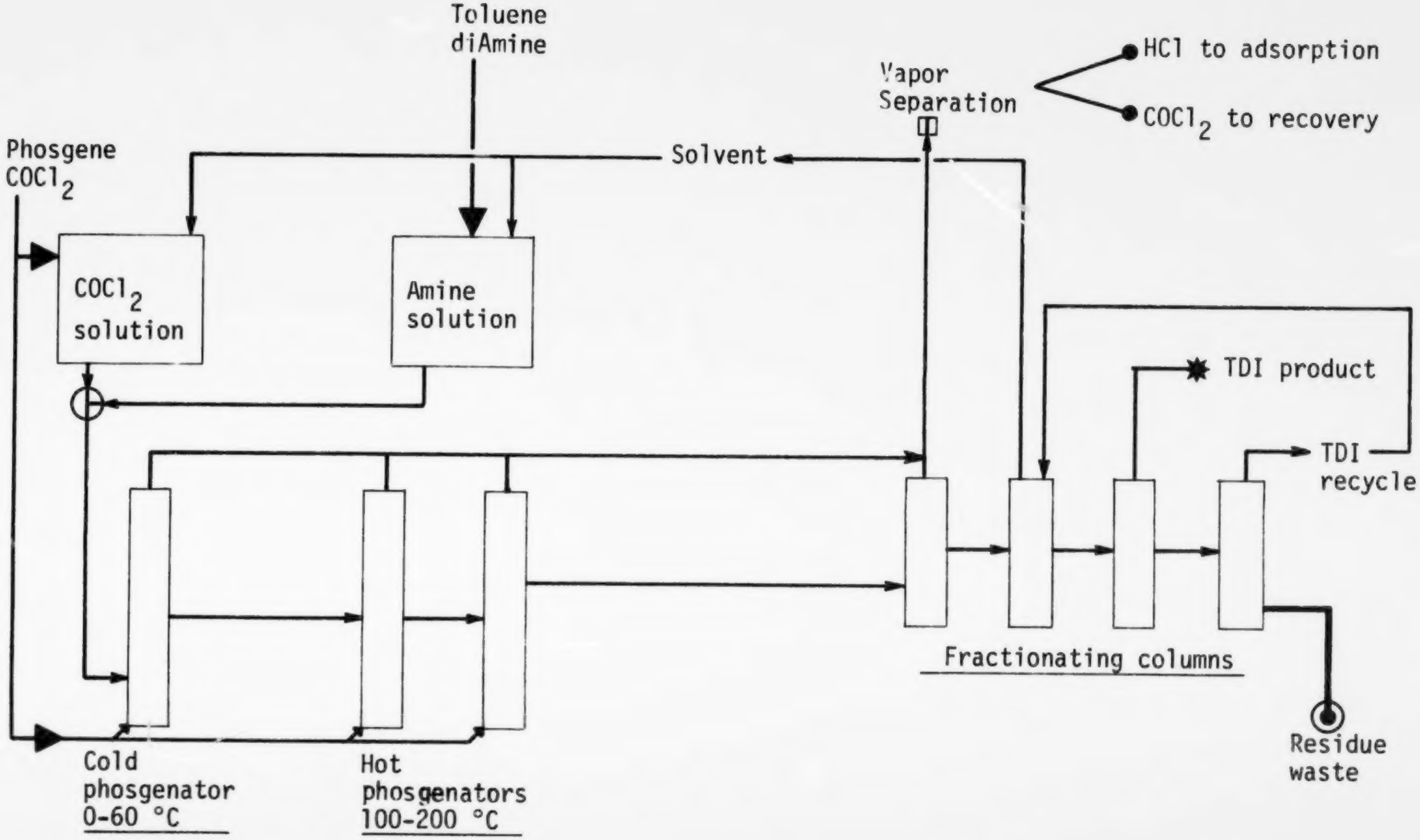
Toluene diAmine
Phosgene $COCl_2$
$COCl_2$ solution
Amine solution
Solvent
Vapor Separation
HCl to adsorption
$COCl_2$ to recovery
TDI product
TDI recycle
Fractionating columns
Residue waste
Cold phosgenator 0-60 °C
Hot phosgenators 100-200 °C

Figure 14. Schematic diagram for manufacture of toluene diisocyanate from toluene and phosgene. (From Reference #36)

themselves. The manufacture of flexible urethane foam utilizes 50 percent of the isocyanates produced, with rigid foam consuming 23 percent, and coatings and elastomers 5 percent. They have been an extremely rapid growth group of chemicals, at 38 percent per year from 1957 to 1967, and with future growth predicted at 10 percent per year through 1972. In 1967 production of isocyanates was 250 million pounds. Production is predicted to be 400 million pounds by 1972.(46)

Toluene diisocyanate is one of the major isocyanates, and is produced from toluene derivatives and phosgene as shown in Figure 14. In this process, toluene diamine is produced by the successive nitration of toluene with mixed nitric and sulfuric acids. The toluene diamine, along with an aromatic solvent such as xylene, monochlorobenzene, or orthene, is mixed with phosgene containing the same solvent. This reaction mixture is digested in one to three stages at progressively higher temperatures with the injection of additional phosgene, The resultant solution is fractionated to recover hydrogen chloride, unreacted phosgene, solvent, and the product toluene diisocyanate (TDI). In the last fractionating column, the remaining TDI is recovered and recycled back to the second fractionating column leaving a waste distillation residue.

Ethyl Chloride. Ethylene-based chemical operations can generate a variety of wastes. Sludges, tars, and filter residues were all reported in the survey as wastes from these operations. An example of an ethylene-based process is the production of ethyl chloride from ethylene and hydrogen chloride. Ethyl chloride is used mainly for production of tetraethyl lead with 675 million pounds produced in 1968.(46)

The process, as shown in Figure 15, brings ethylene gas and anhydrous hydrogen chloride together in approximately equimolecular proportions. The mixture is passed into a reactor containing ethylene dichloride or a mixture

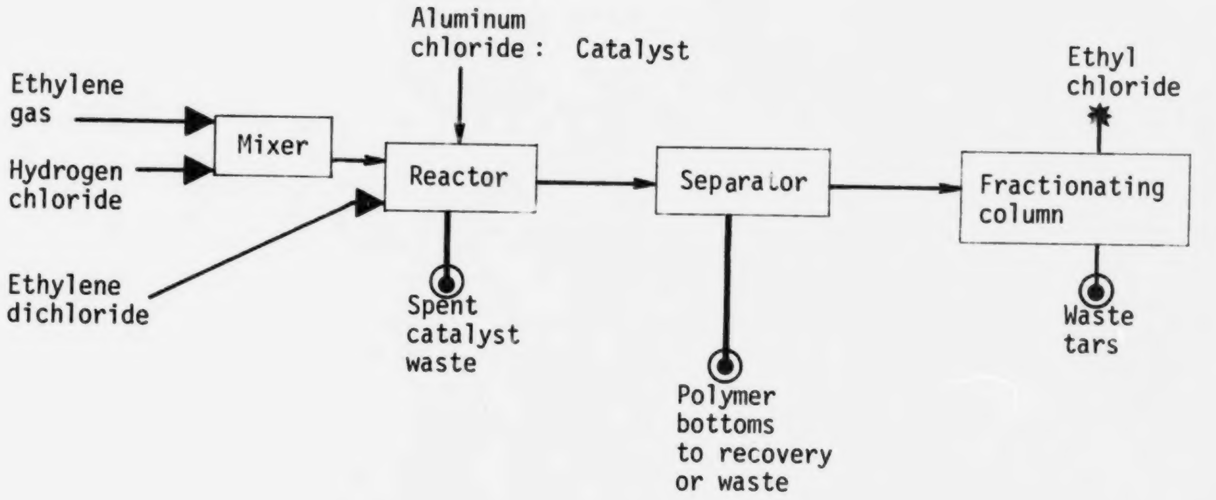
Aluminum chloride : Catalyst
Ethylene gas
Hydrogen chloride
Ethylene dichloride
Mixer
Reactor
Spent catalyst waste
Separator
Polymer bottoms to recovery or waste
Fractionating column
Ethyl chloride
Waste tars

Figure 15. Schematic diagram for manufacture of ethyl chloride from ethylene and hydrogen chloride. (From Reference #26)

of ethyl chloride and ethylene dichloride. The hydrochlorination reaction takes place in the presence of a catalyst, aluminum chloride. The catalyst is continually withdrawn and new makeup catalyst added with some of the spent catalyst discarded. The reactor products are fed into a separator where the lower boiling ethyl chloride is separated from the heavier polymers which are drawn off and either partially recovered or wasted. The crude ethyl chloride is further refined by fractionation, removing other high boiling organics to waste.

Chloral. A waste sludge is generated from chloral production from ethyl alcohol by chlorination. Chloral is used chiefly in the production of DDT. Ethyl alcohol is first chlorinated, during which ethyl chloride is obtained as a byproduct. The chlorinated mixture consists of chloral hydrate and chloral hemiacetal. It is mixed with sulfuric acid to decompose the acetal. The mixture is then distilled and the chloral cut taken off. The resultant crude or technical-grade chloral may be used directly in the manufacture of DDT, or it may be further refined. The refining procedure uses calcium carbonate to remove the remaining traces of acid. A waste sludge of calcium sulfate is formed and drawn off to disposal.

Citric Acid. Organic chemicals from other than coal or oil derivatives can also generate solid waste. Citric acid is an organic acid, produced from sugar, whose production generates solid waste. Its uses include: beverages, 60 percent; pharmaceuticals, 18 percent; and sodium salts and esters, 10 percent.(46)

Mycological fermentation of carbohydrates is the most important commercial source of citric acid. It also occurs naturally in citrus fruits and pineapple, from which it is sometimes recovered. The mycological processes are complicated fermentation processes where the factors governing citric acid accumulation are controlled to obtain maximum yields.

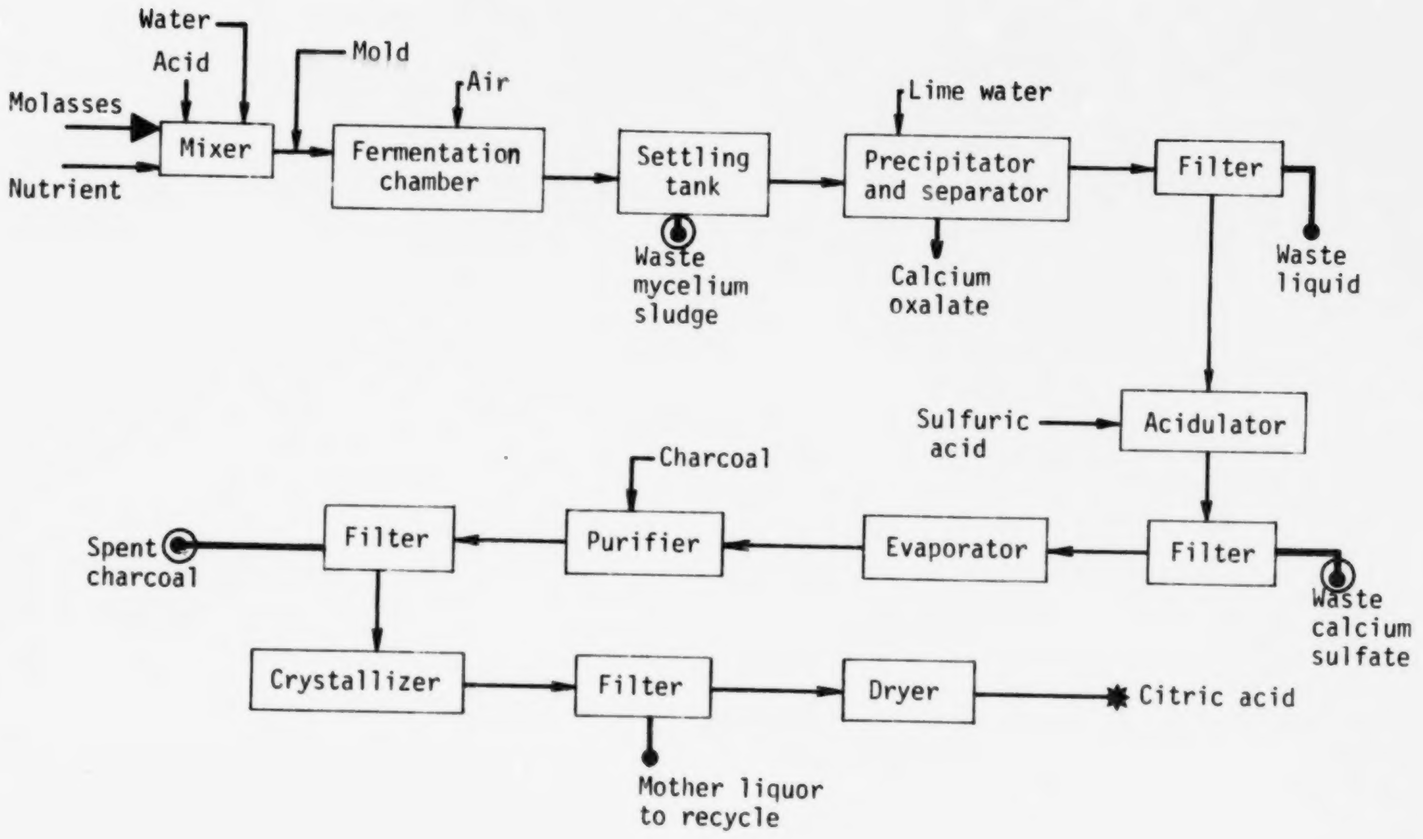
Water
Acid
Molasses
Nutrient
Mixer
Mold
Air
Fermentation chamber
Settling tank
Waste mycelium sludge
Lime water
Precipitator and separator
Calcium oxalate
Filter
Waste liquid
Sulfuric acid
Acidulator
Filter
Waste calcium sulfate
Evaporator
Charcoal
Purifier
Filter
Spent charcoal
Crystallizer
Filter
Mother liquor to recycle
Dryer
Citric acid

Figure 16. Schematic diagram for manufacture of citric acid from molasses by fermentation. (From Reference #26)

The process as shown in Figure 16 uses a molasses to supply the necessary carbohydrates, water, acid, and a nutrient to which a mold is added to induce fermentation. The mixture is retained in the fermentation chamber until sufficient mycelium has formed. The solution is withdrawn from the chamber, and the mycelium settled out, washed, and filtered to remove residual adhering citric acid. Calcium hydroxide is added to neutralize the solution, and the calcium citrate is filtered off and washed to remove adherent residual sugar, polysaccharides, and nitrogenous constituents. The filtrate, a liquid waste, is sent to disposal. The calcium citrate is sent to an acidulation tank where a slight excess of sulfuric acid is added. This combination forms dilute citric acid and calcium sulfate. The calcium sulfate is filtered off and washed on a filter. The dilute citric acid is purified by decolorization and demineralization. This process involves treatment with activated carbon followed by final filtration. The carbon is either wasted or reactivated and returned to the process. The solution is then crystallized and the mother liquor removed and returned to the process. The solid wastes from this process are the mycelium removed as a filter cake, the hydrated calcium sulfate also removed as a filter cake, and occasionally the spent carbon. Ergosterol has been obtained commercially from the mycelium, but it still remains of little commercial value. An additional filter cake waste associated with this process is generated from the purification of the syrup used as the raw material.

Inorganic Chemicals

Unlike organic chemicals, whose primary derivation is from two basic raw materials, coal and oil, inorganic chemicals are derived from numerous raw materials, including atmospheric gases, minerals, water, and other inorganic matter. The major raw materials of this industry are listed below:

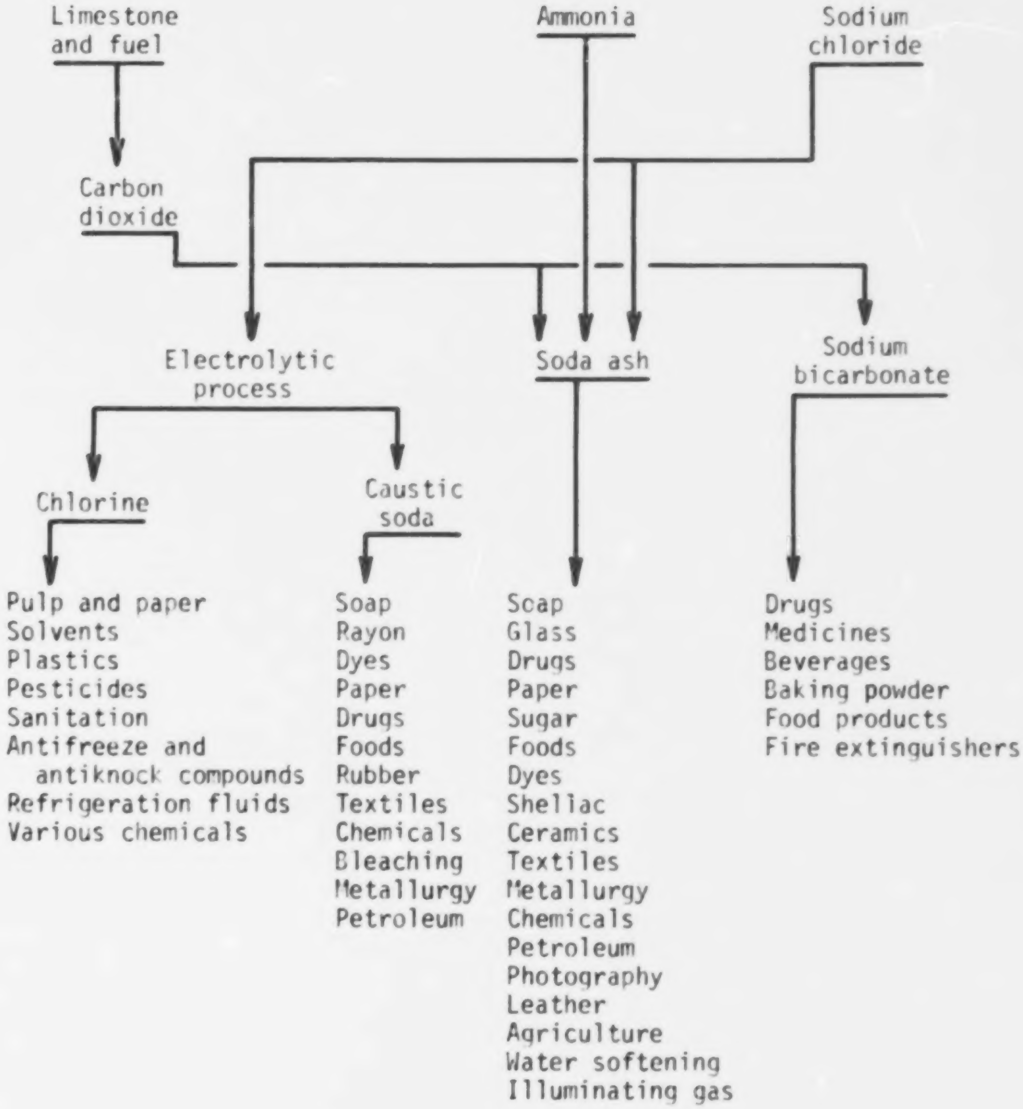
Limestone and fuel
Ammonia
Sodium chloride
Carbon dioxide
Electrolytic process
Soda ash
Sodium bicarbonate
Chlorine
Caustic soda
Pulp and paper
Solvents
Plastics
Pesticides
Sanitation
Antifreeze and antiknock compounds
Refrigeration fluids
Various chemicals
Soap
Rayon
Dyes
Paper
Drugs
Foods
Rubber
Textiles
Chemicals
Bleaching
Metallurgy
Petroleum
Soap
Glass
Drugs
Paper
Sugar
Foods
Dyes
Shellac
Ceramics
Textiles
Metallurgy
Chemicals
Petroleum
Photography
Leather
Agriculture
Water softening
Illuminating gas
Drugs
Medicines
Beverages
Baking powder
Food products
Fire extinguishers

Figure 17. The alkalies and chlorine industry. (From Reference #58)

NON-METALS

Limestone
Sulfur
Phosphorus
Air
Salt
Sand
Clays
Water

METALS

Lead
Zinc
Copper
Iron
Boron
Chromium
Manganese
Lithium
Aluminum
Other ores

The industry has been divided into four categories: alkalies and chlorine (SIC #2812), industrial gases (SIC #2813), inorganic pigments (SIC #2816), and miscellaneous inorganic chemicals N.E.C. (SIC #2819). These categories include some of the very largest production chemicals such as ammonia, chlorine, and sulfuric acid. The numbers of different chemicals within the industry are not as great as the number encompassed by the organic industry, however; there are only 30,000 inorganics vs. about one million organic compounds.

Solid Waste Generation-Alkalies and Chlorine Industry (SIC #2812). This industry, although it contains relatively few chemicals, is one of the most important, producing many of the basic chemicals used in the manufacture of many other industrial chemicals and allied products. In terms of dollar value, these chemicals rank near the top of all the inorganic chemicals.

The major raw materials used in the industry are shown in Figure 17, along with the four most important chemicals-chlorine, caustic soda, soda ash, and sodium bicarbonate-and some of the important products requiring these chemicals for manufacture. Production of the important chemicals is shown in Table 20.

Soda Ash and Sodium Bicarbonate. Soda ash and sodium bicarbonate are the two most important chemicals of this group in terms of solid waste generation. Both chemicals are produced together, in the same process, with soda ash obtained from the bicarbonate in a final calcining step. Soda ash has by far the largest

TABLE 20

PRODUCTION OF CHLORINE AND ALKALIES-1963 AND 1967*

Chemical	Production Short tons	
	1963	1967
Chlorine (gas and liquid)	8,380,000	11,600,000
Caustic soda (sodium hydroxide)	5,810,000	7,920,000
Soda ash (sodium carbonate)**	4,460,000	4,700,000
Sodium bicarbonate	108,000	128,000
Potassium hydroxide	130,000	175,000

*From Reference #65.

**Not including natural soda ash.

volume of the two with 6,400,000 tons produced in 1966 and 7,160,000 tons predicted for 1970. Its growth rate was 3.1 percent per year from 1955 to 1965, and was expected to continue at 3 percent through 1970. Uses include: glass manufacture, 44 percent; chemicals, 25 percent; pulp and paper, 9 percent; along with soap and detergents, aluminum, and water treatment.(46) It is probable that future increases in demand for this chemical will be met by natural soda ash, since costs for construction of synthesizing plants are high and the last synthesis plant was built in 1934.

Sodium bicarbonate production was 128,000 tons in 1967, growing at a rate of only 2.3 percent from 1956 to 1966. Its uses include the food industry, 40 percent; chemicals, 14 percent; and pharmaceuticals, 13 percent.(46)

Two sources of these chemicals exist: from natural deposits and brines, particularly in California and Wyoming, and from the Solvay or ammonia-soda process, which is the major source today.

The Solvay process generates large volumes of solid wastes. A flow chart for this process is shown in Figure 18. An almost saturated sodium chloride solution, which is usually taken from underground salt deposits, is the source of salt for the process. Sea water contains too many impurities and is seldom used. The brine is first purified by adding lime or soda ash to precipitate calcium carbonate, magnesium carbonate and hydroxide, and iron hydroxide. Settling vats remove the precipitates, which are sent to waste disposal. The clarified brine flows to a strong ammonia absorber where it takes up the necessary ammonia. The ammonia acts as a catalyst throughout the process. The ammonia-brine solution flows to a carbonating tower containing rich carbon dioxide gas. The carbon dioxide is obtained from a lime kiln which calcines limestone mixed with coke. In the carbonator, aqueous ammonium hydroxide reacts with the carbon dioxide to form ammonium carbonate, and then with water to form

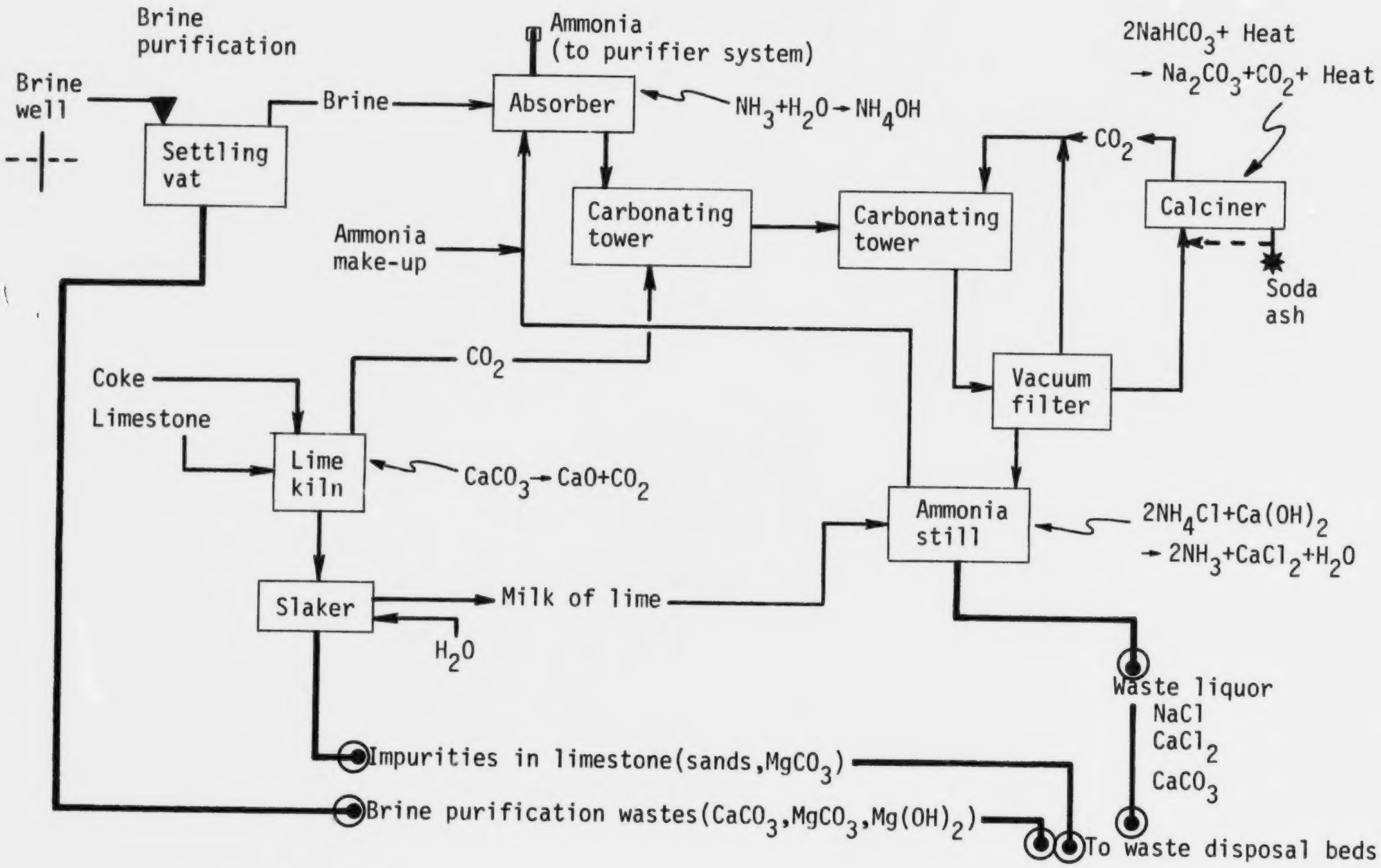
Brine purification
Brine well
Settling vat
Brine
Absorber
Ammonia (to purifier system)
$NH_3+H_2O \rightarrow NH_4OH$
Ammonia make-up
Carbonating tower
Carbonating tower
CO_2
Calciner
$2NaHCO_3+$ Heat $\rightarrow Na_2CO_3+CO_2+$ Heat
Soda ash
Vacuum filter
Coke
Limestone
CO_2
Lime kiln
$CaCO_3 \rightarrow CaO+CO_2$
Ammonia still
$2NH_4Cl+Ca(OH)_2 \rightarrow 2NH_3+CaCl_2+H_2O$
Slaker
Milk of lime
H_2O
Waste liquor
$NaCl$
$CaCl_2$
$CaCO_3$
Impurities in limestone(sands,$MgCO_3$)
Brine purification wastes($CaCO_3$,$MgCO_3$,$Mg(OH)_2$)
To waste disposal beds

Figure 18. Schematic diagram for manufacture of soda ash by the Solvay Process.

ammonium bicarbonate. The ammonium bicarbonate reacts with sodium chloride brine to form ammonium chloride and sodium bicarbonate. This is a liquid-gas absorption with the precipitation of the sodium bicarbonate. The crude sodium bicarbonate is removed by vacuum filtration and washed on a drum to remove salt and ammonium chloride. The washed sodium bicarbonate can either be sold directly or calcined to obtain soda ash. The liquor from the bicarbonate vacuum filter is fed to a strong ammonia liquor still for ammonia recover.

The economical operation of the Solvay process depends upon the efficiency of ammonia recovery. At any time the value of the ammonia in the system is several times the value of the soda ash produced. Milk of lime is added to the ammonia still to free the ammonia. The ammonia-free liquor contains about 50 g/liter of residual and unreacted sodium chloride, along with some of the formed calcium chloride and some calcium carbonate in suspension. The mixture is sent to the waste disposal area.

The milk of lime is obtained from the lime kiln after the impurities have been removed by the slaker. These impurities are mainly those existing in the original limestone, and consist of sands and magnesium carbonate. This source generates the largest volume of waste from the process, with the amount depending on the purity of the limestone used.

All of these wastes, from the lime slaker, the ammonia still, and brine purification, are slurries containing suspended solids. The wastes are usually sent to large diked waste beds where the solids settle out and the clarified liquor overflows to a water body. As the diked areas fill up with solids, they are abandoned and new ones used.

Chlorine and Caustic Soda. Chlorine and caustic soda (sodium hydroxide) are both produced from salt solution by electrolysis. The process usually employs diaphragm or mercury cells where chlorine is liberated at the anode and caustic soda at the carthode. Chlorine is a very important basic chemical, with 53 percent of production going to organic chemical and 12 percent to inorganic chemical manufacture. The other large use is for disinfection in the water treatment and sewage treatment fields.

Production of chlorine in 1967 was 7.5 million tons, and the growth rate should be at 7 percent per year through 1971. The largest portion of caustic soda (40 percent) is also used in the manufacture of other chemicals. Production in 1967 was 7.7 million tons with a predicted growth rate of 5 percent per year through 1971.(46)

Chemical solid wastes from the electrolytic process itself are not significant. A small amount results from salt solution purification. The diaphragm cells, however, must be dismantled periodically for diaphragm replacement. This is a good example of solid wastes resulting from necessary equipment replacement in which the parts cannot be salvaged. The diaphragm cells are composed of concrete slabs in a roughly cubical arrangement. The cells contain a porous asbestos diaphragm to separate the anode from the cathode. This diaphragm allows ions to pass through by electrical migration, but reduces diffusion of products. Diaphragms become clogged with use, as indicated by higher voltage and hydrostatic pressure on brine feed, and must be replaced every 100 to 200 days. The anodes are graphite plates, and the cathodes are crimped steel wire. The spent graphite plates are sold to salvage, and the cathodes are either salvaged or discarded. The concrete slabs, the body of the cell, are dumped in piles on land. In many cases, they have been used as rip-rap on river banks.

Solid Waste Generation-Industrial Gases (SIC #2813) Oxygen, Nitrogen, Hydrogen, and Carbon Dioxide. Industrial gases have many applications, from essential ingredients in the manufacture of other chemicals to food additives. Oxygen, nitrogen, and hydrogen are the three most important gases used as raw materials for other chemicals. Nitrogen is also used to preserve the flavor of packaged foods and for refrigerated transport. One of the fastest growing uses of these gases is in cryogenics, which is the production and use of extreme cold at the range of temperatures below -150 F. Oxygen is finding new areas of application in pollution control, such as increasing combustion efficiency and treatment of waste water.

The predominant raw materials used for production of industrial gases are natural gas and atmospheric air. An outline of the processes used to obtain the gases is shown in Figure 19. Carbon dioxide is produced from burning natural gas, or in some cases fuel oil or coke, and by extracting the carbon dioxide from the flue gases. It is also produced as a byproduct from fermentation and lime kiln operations. Natural gas is used to produce acetylene by pyrolysis through either partial oxidation, thermal cracking, or electric arc methods. Acetylene is also produced from the reaction of calcium carbide with water.

A variety of methods exist for production of hydrogen. The most prominent is steam-hydrocarbon reforming of natural gas. The air separation plant is the main source of oxygen, nitrogen, and the rare gases. The principal gas produced is oxygen, the highest volume industrial gas. Nitrogen is actually a byproduct of oxygen production, and the rare gases of argon, helium, neon, xenon, and krypton are obtained by side rectification columns from takeoffs at various points in the air separation process. The quantities of the major industrial gases produced in 1963 and 1967 are shown in Table 21.

Oxygen is produced both as lower purity or tonnage oxygen (95 percent to 99 percent pure) and high purity (99.5 percent pure). High purity is preferred for medicinal use, ammonia, acetylene, ethylene oxide, and missile fuel. The tonnage grade makes up about two-thirds of total oxygen production, with the steel manufacturing industry its largest consumer. Carbon dioxide is the second

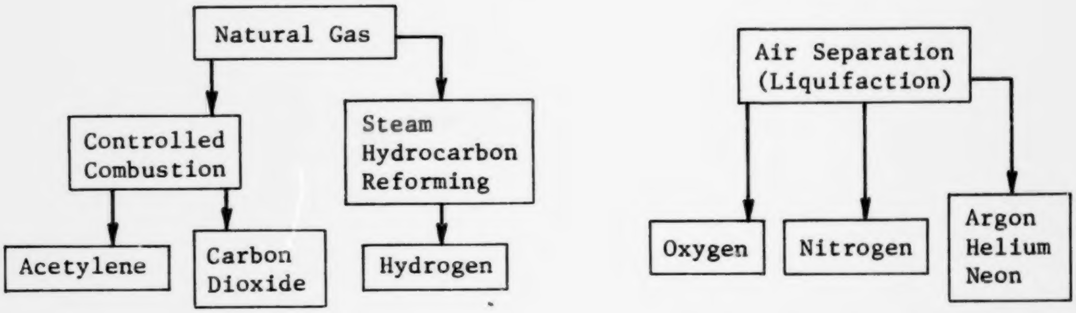
Natural Gas
Controlled Combustion
Steam Hydrocarbon Reforming
Acetylene
Carbon Dioxide
Hydrogen
Air Separation (Liquifaction)
Oxygen
Nitrogen
Argon Helium Neon

Fig. 19. Major production processes for industrial gases.

TABLE 21

PRODUCTION OF INDUSTRIAL GASES-1963 AND 1967*

Gas		United of measure	Production 1963	Production 1967
Oxygen	high purity	Million cu. ft.	128,000	243,000
	lower purity	Short tons	1,940,000	1,970,000
Carbon dioxide		Short tons	977,000	1,080,000
Hydrogen		Million cu. ft.	95,600	158,000
Acetylene		Million cu. ft.	14,700	14,300
Nitrogen		Million cu. ft.	50,900	104,000
Argon		Million cu. ft.	970	1,910

*From Reference #65.

largest volume industrial gas, with over a million short tons produced in 1967. Considerable growth occurred in this industry from 1963 to 1967, with high purity oxygen, hydrogen, nitrogen, and argon leading with increases of 82 percent, 65 percent, 105 percent, and 97 percent, respectively.(65)

Acetylene. Except for acetylene, production of the industrial gases does not produce significant quantities of solid wastes. The air separation plants are particularly clean operations. Acetylene production generates large solid waste quantities using any of three major processes: the Wulff, calcium carbide, and Sachsse processes. The gas is used for manufacture of vinyl chloride monomer, 50 percent; vinyl acetate monomer, 24 percent; and for neoprene, acrylates, and acrylonitrile. In 1967, 590 million pounds of acetylene were produced. Its growth rate from 1961 through 1967 was 23 percent per year, but through 1972 it is predicted to be only 0.3 percent per year.(46)

The production process utilizing calcium carbide as a raw material generates large quantities of calcium hydroxide, most of which may end up as waste. Calcium carbide is formed from a mixture of lime and coke heated in an electric furnace. In the acetylene production process, water is added to the calcium carbide according to the following reaction:

calcium carbide + water = calcium hydroxide + acetylene

There are two different processes based on the amount of water used. The wet process consists of adding large quantities of water to the calcium carbide, with the calcium hydrate residue discharged in the form of a lime slurry containing approximately 90 percent water.

The dry process adds a limited amount of water to the calcium carbide. The heat of reaction vaporizes the excess water, leaving a dry calcium hydrate. The large quantities generated along with the other abundant supplies of lime available make it difficult to use all the calcium hydrate generated. The present uses for this waste are discussed in Section Six.

The Wulff process for acetylene manufacture is shown in Figure 20. The process operates by the thermal decomposition of hydrocarbons such as methane, ethane, propane, butane, ethylene, and natural gas. The hydrocarbon feed stock is first pyrolized in a furnace, and the products are then quenched in a tar trap where various tars are removed. This process is followed by compression and further tar removal by an electrostatic precipitator. The gases are then purified to recover acetylene.

Other processes produce acetylene from high temperature cracking of hydrocarbon feed stocks such as natural gas, LPG, naphtha, fuel oil, and crude oil. The Sachsse process, as shown in Figure 21, uses methane (natural gas) as the feed stock. The methane is partially oxidized with oxygen with the excess methane cracked to acetylene by the heat evolved. The resultant gases are quenched with water and run to a filter where carbon black is removed on a moving bed of coke. Carbon black is also contained in the quench water. About 52 pounds of carbon black is removed per ton of acetylene produced(26) and most of this material is wasted. The clean gas is purified using procedures similar to that of the Wulff process.

An electric arc has also been utilized for hydrocarbon cracking to form acetylene. The arc burners developed are said to have high acetylene yields with lower carbon black and other byproducts.

Solid Waste Generation-Inorganic Pigments (SIC #2816). Paints are pigmented liquid compositions containing film-forming materials, thinners, driers, antiskinning agents, plasticizers, and extenders. The function of pigments is to protect the paint film by reflecting destructive ultraviolet light, to strengthen the film, and to give the paint its color. Pigments are generally inorganic substances, but they may also be pure organic dyes called

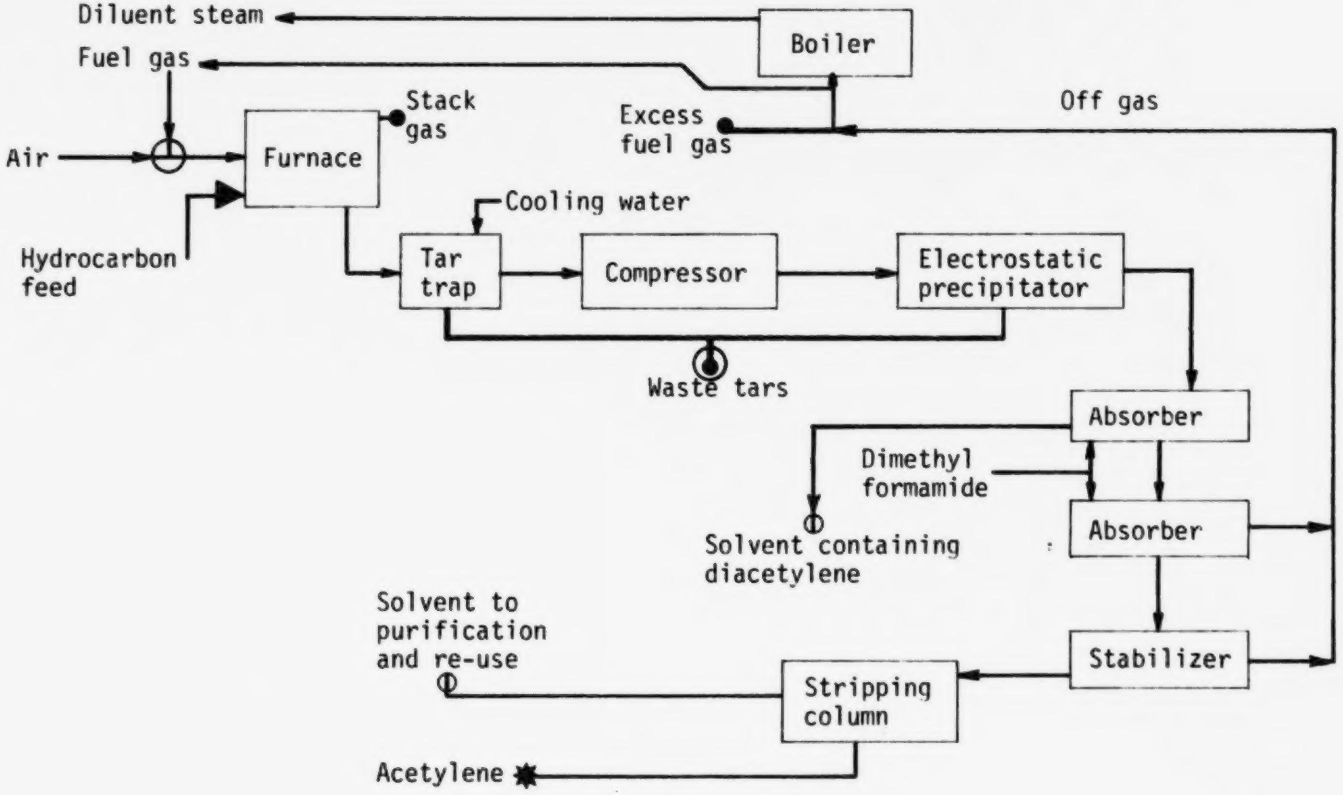
Diluent steam
Boiler
Fuel gas
Stack gas
Excess fuel gas
Off gas
Air
Furnace
Cooling water
Hydrocarbon feed
Tar trap
Compressor
Electrostatic precipitator
Waste tars
Absorber
Dimethyl formamide
Solvent containing diacetylene
Absorber
Solvent to purification and re-use
Stabilizer
Stripping column
Acetylene

Figure 20. Schematic diagram for manufacture of acetylene from paraffin hydrocarbons by pyrolysis. (Wulff Process). (From Reference #26)

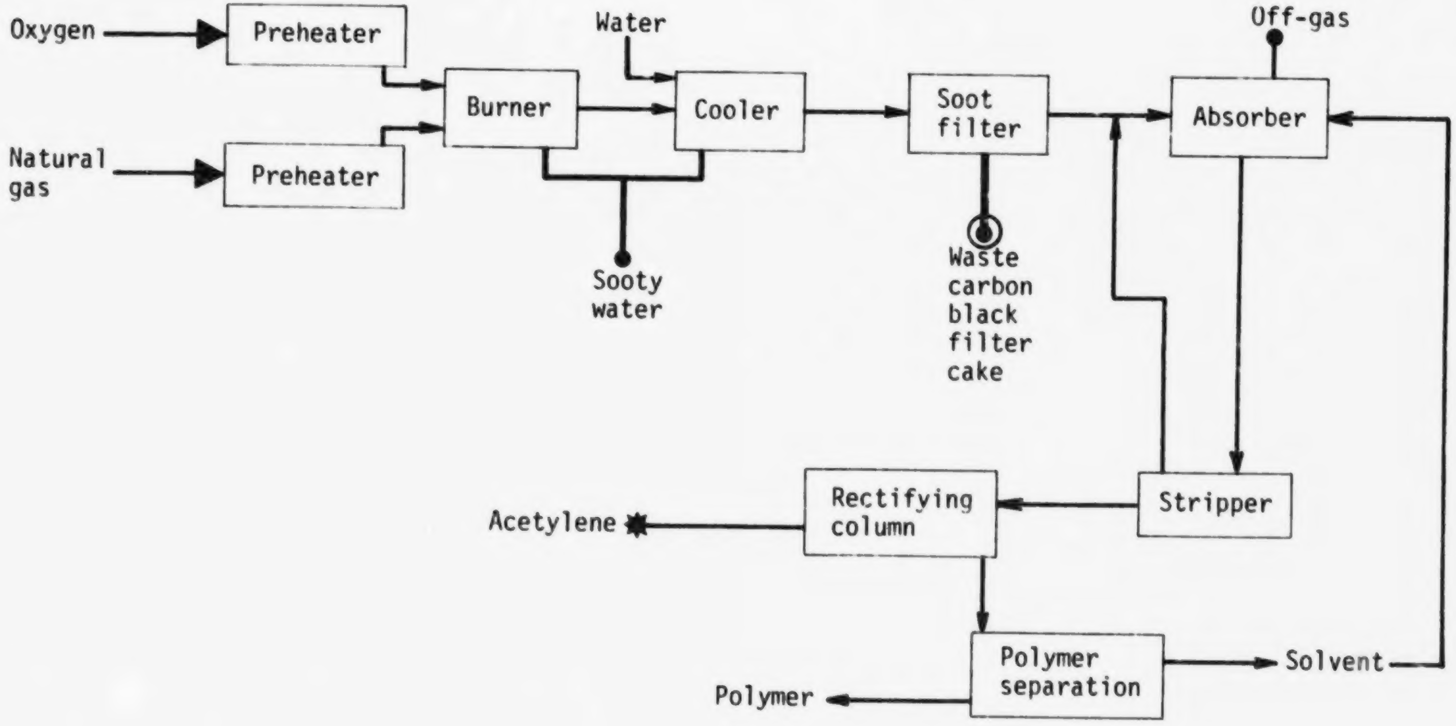
Oxygen
Preheater
Natural gas
Preheater
Burner
Water
Cooler
Sooty water
Soot filter
Waste carbon black filter cake
Off-gas
Absorber
Stripper
Rectifying column
Acetylene
Polymer separation
Solvent
Polymer

Figure 21. Schematic diagram of manufacture of acetylene from natural gas by partial oxidation. (Sachsse Process). (From Reference #26)

TABLE 22

MAJOR INORGANIC PIGMENTS
SIC 2816
1963 AND 1967*

Pigment	Production 1963 Short tons	 1967 Short tons
Titanium dioxide (composite and pure) (100% titanium dioxide)	519,000	589,000
Chrome green (chrome yellow and iron blue) (C.P.)	2,870	2,740
Chrome oxide green (C.P.)	5,220	5,190
Chrome yellow and orange (C.P.)	24,700	30,700
Molybdate chrome orange (C.P.)	8,440	10,400
Zinc yellow (zinc chromate) (C.P.)	6,860	7,800
Iron blues (Prussian blue)	5,030	5,580
Other major pigments: White lead, Litharge, Red lead, Zinc oxide		

*From Reference #65.

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toners, or organic dyes precipitated on an inorganic carrier, such as aluminum hydroxide, barium sulfate, or clay, called a lake. The major inorganic pigments are listed in Table 22.

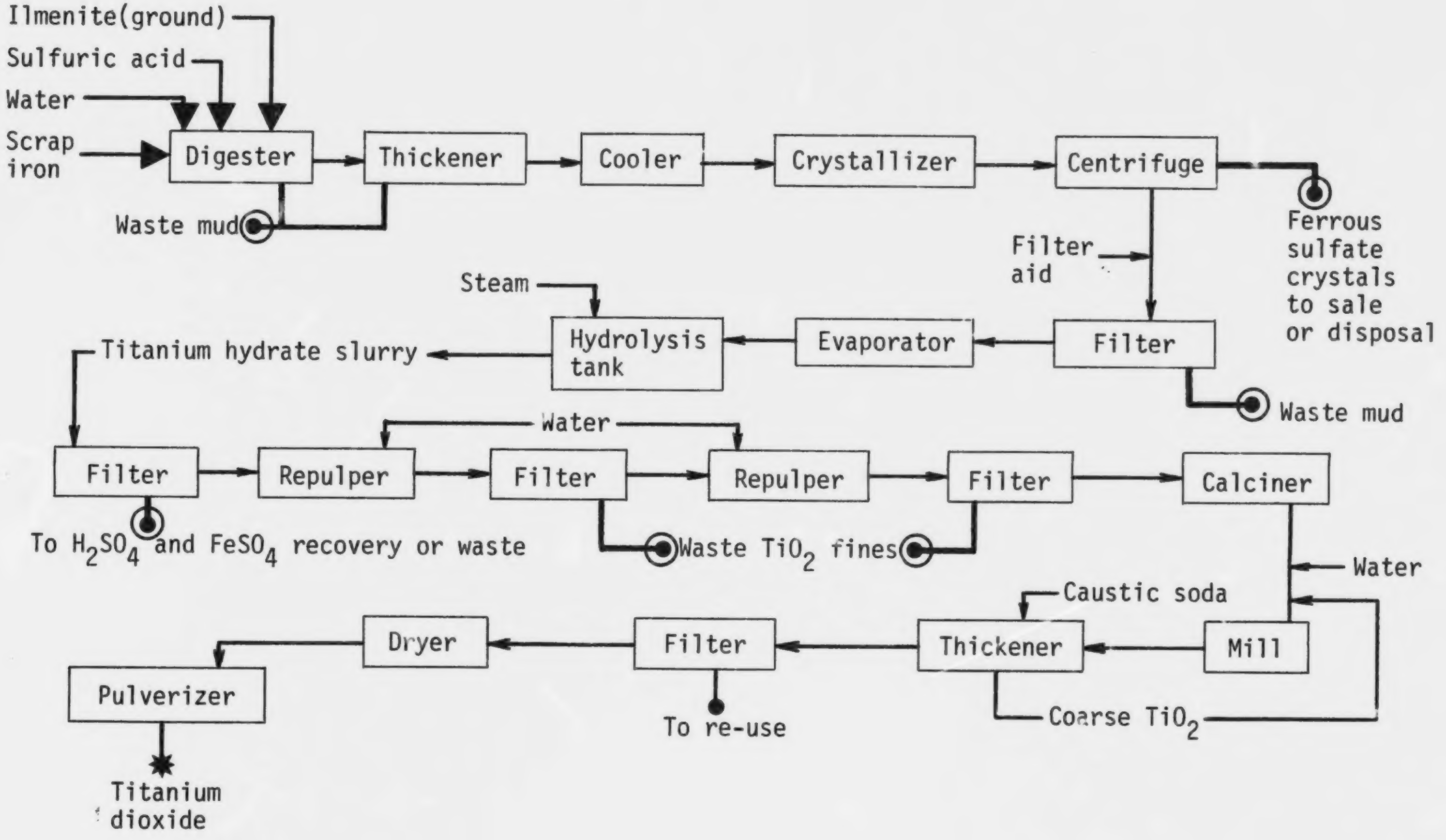
The major raw materials for inorganic pigment production are ores containing the necessary metal, a metal compound, or the metal itself. When an ore is the raw material, the metal must be extracted in the form necessary for pigment production, such as in the manufacture of titanium dioxide, the most widely used inorganic pigment. Impurities in the ores used can result in large quantities of solid wastes.

Metal Based Pigments. Red lead is an example of a pigment produced from a metal. One method of manufacture is to oxidize lead to litharge (Pbo) in air, and then further oxidize the litharge to red lead. In another process, called the fumed process, lead is atomized by compressed air, then forced through the center of a gas flame, converting the lead to litharge which is then further oxidized to red lead. Few impurities are present in the metallic lead, and consequently little, if any, solid waste is produced from these processes.

Metal Compound Based Pigments. The compound ferrous sulfate is used to produce iron blue pigments. Ferrous sulfate solutions are precipitated with sodium ferrocyanide giving a white ferrous ferrocyanide, or ferrocyanide blues. The most popular class of yellow pigments, chrome yellows, are produced by mixing a solution of lead nitrate or acetate with a solution of sodium dichromate.

Ore Based Pigments. Titanium dioxide is an example of a pigment whose manufacturing process generates large quantities of solid wastes, mainly ore impurities. It is the largest seller of all white pigments, with 589,000 short tons produced in 1967 and a predicted demand of 790,000 tons in 1970.(46)

Either the sulfuric acid or the hydrochloric acid process (also known as the sulfate or chloride processes) is generally used. The sulfuric acid



Ilmenite(ground)
Sulfuric acid
Water
Scrap iron
Digester
Thickener
Cooler
Crystallizer
Centrifuge
Waste mud
Ferrous sulfate crystals to sale or disposal
Filter aid
Steam
Hydrolysis tank
Evaporator
Filter
Waste mud
Titanium hydrate slurry
Water
Filter
Repulper
Filter
Repulper
Filter
Calciner
To H_2SO_4 and $FeSO_4$ recovery or waste
Waste TiO_2 fines
Water
Caustic soda
Dryer
Filter
Thickener
Mill
Pulverizer
To re-use
Coarse TiO_2
Titanium dioxide

Figure 22. Schematic diagram for manufacture of titanium dioxide from ilmenite. (From Reference #26)

process is shown in Figure 22. This process uses ground ilmenite as the titanium ore, generally 50 to 70 percent titanium dioxide. The ore is digested hot in sulfuric acid, and the resulting sulfates of iron and titanium are leached from the reaction mass with water. Both ferrous and ferric sulfates are formed, with the ferric ion reduced to ferrous by treatment with scrap iron. The solution is then drawn out of the digester, leaving a residue of unreacted ore. The residue is a mud containing silica, some titanium oxide, and other insoluble matter. The mud is disposed of via landfill, or in some cases, hauled to sea.

The solution is clarified in a thickener, with generation of more waste mud, and sent to a vacuum cyrstallizer. Ferrous sulfate (copperas) crystallizes out of solution and is separated by centrifuging. There is a small market for this copperas, but most of it must be disposed of at sea. The remaining liquor is filtered to remove the impurities, which, as a mud, are sent to disposal. The filtrate is heated, and the titanium content hydrolizes to insoluble titanium hydroxide. It is washed and filtered, and the final filter cake is calcined to yield titanium dioxide. The titanium dioxide is milled and dried to form anatase titanium dioxide. The filtrate from the first filter contains ferrous sulfate which did not crystallize and is wasted or recovered along with sulfuric acid.

The wash water from the filters contains titanium dioxide fines. The water can be sent to recovery operations or directly to disposal. In some cases, the waters are sent to lagoons where the titanium dioxide settles out. The lagoons are periodically dredged, and the titanium dioxide mud stored for possible recovery if economic conditions permit.

The choloride process uses rutile ore (See Figure 23) which is 90-95 percent pure titanium dioxide with the remainder principally iron oxide and silica. It also generates a waste mud consisting mainly of impurities in the ore. In the process, chlorine, coke, and rutile ore are heated in a chlorination furnace

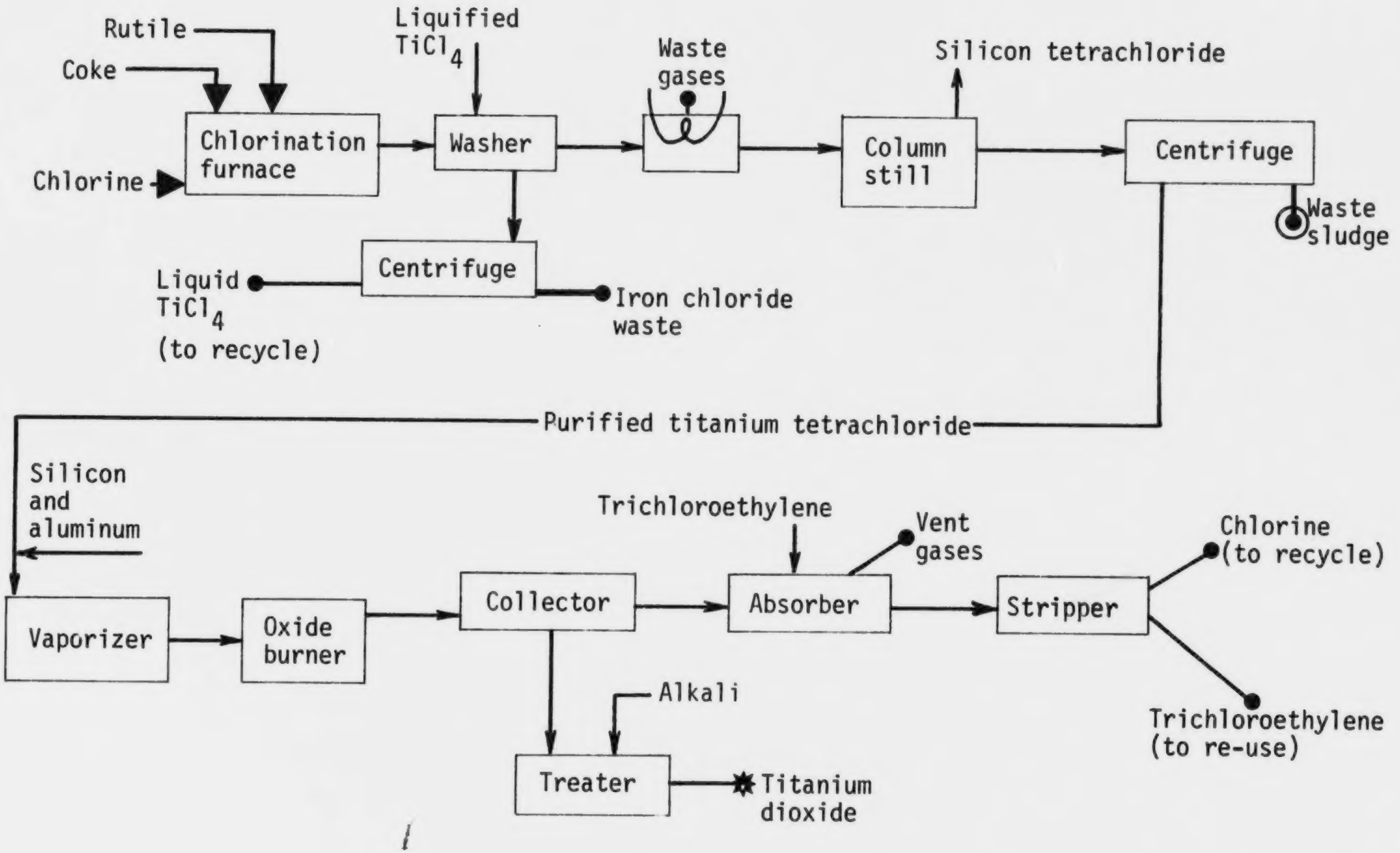

Rutile
Coke
Chlorine
Chlorination furnace
Liquified $TiCl_4$
Washer
Waste gases
Silicon tetrachloride
Column still
Centrifuge
Waste sludge
Centrifuge
Liquid $TiCl_4$ (to recycle)
Iron chloride waste
Purified titanium tetrachloride
Silicon and aluminum
Vaporizer
Oxide burner
Collector
Trichloroethylene
Absorber
Vent gases
Stripper
Chlorine (to recycle)
Trichloroethylene (to re-use)
Alkali
Treater
Titanium dioxide

Figure 23. Schematic diagram for manufacture of titanium dioxide from rutile by chlorination and oxidation. (From Reference #26)

to produce titanium tetrachloride. From the furnace, the material is washed with liquified titanium chloride which solidifies and precipitates the iron chloride. The iron chloride is removed by centrifuging as a solid waste. The filtrate is passed through a column still, silicon tetrachloride is driven off, and the remaining impurities are removed by a centrifuge. These impurities are a titanium-rich waste which is added to the iron chloride for disposal. The titanium chloride is hydrolized and converted to titanium dioxide in a flame of oxygen and fuel gas.

Another example of a pigment produced from an ore is barium sulfate, used principally for its stability. The pigment is produced from barytes ore, and leaves a wet filter cake of ore impurities which must be discarded. Zinc oxide production, using the American or direct process, also generates a waste of ore impurities. Crushed Franklinite ore is mixed with anthracite coal and fed to a furnace. Zinc vapors are released from the ore and oxidized with air under controlled conditions to yield finely divided particles of zinc oxide. The Franklinite ore is composed of manganous, ferrous, manganic, and ferric oxides, along with the zinc oxides which account for 20 percent of the ore. These impurities remain in the furnace as a residue along with unburned coal. The clinker is either dumped as a waste or in some instances used for the manufacture of Spiegeleisen, a manganese alloy useful in steel making.

Solid Waste Generation-Miscellaneous Inorganic Chemicals (SIC #2819). This group of chemicals, containing many thousands of chemicals derived from numerous raw materials, is the largest within the inorganic chemical industry. The raw materials are found in many different mediums including ores, underground deposits, sands, and sea water.

Within this chemical group are a number of chemical families consisting of compounds of a basic inorganic chemical. These families are listed in Table

TABLE 23

MAJOR INORGANIC CHEMICALS
SIC 2819
PRODUCTION 1963 AND 1967*

Chemical	Production	
	1963 Short tons	1967 Short tons
Aluminum compounds		
Aluminum oxide (except natural alumina) (100%)	4,820,000	6,050,000
Aluminum sulfate	1,010,000	1,100,000
Aluminum hydroxide (100%)	230,000	275,000
Aluminum chloride	51,800	60,200
Ammonium compounds		
Ammonium nitrate (100%)	3,990,000	5,710,000
Ammonium chloride	22,500	**
Ammonia (100%)	6,750,000	12,300,000
Ammonium sulfate (100%)	1,200,000	1,940,000
Calcium compounds		
Calcium carbide	1,110,000	912,000
Calcium carbonate (100%)	159,000	190,000
Calcium chloride	916,000	1,170,000
Calcium phosphates (100%)	240,000	392,000
Iron compounds		
Ferric chloride (100%)	37,000	38,600
Ferrous sulfate	160,000	197,000
Phosphorus compounds		
Phosphorus oxychloride (100%)	23,900	32,800
Phosphorus pentasulfide (100%)	34,000	48,700
Phosphorus trichloride (100%)	26,800	51,100
Phosphorus elemental	488,000	587,000
Phosphoric acid (100%)	2,900,000	5,190,000
Potassium compounds		
Potassium sulfate (100%)	244,000	244,000
Sodium compounds		
Sodium silicates	865,000	926,000
Sodium chlorate (100%)	124,000	155,000
Sodium (metal) (100%)	126,000	164,000
Sodium phosphates	1,110,000	1,370,000
Sulfur compounds		
Sulfur (elemental) (long tons)	893,000	1,270,000
Sulfur dioxide (produced for sale) (100%)	73,200	96,300
Sulfuric acid (100%)	20,900,000	28,800,000
Miscellaneous inorganic acids		
Hydrochloric acid	1,050,000	1,620,000
Boric (boracic) (100%)	104,000	122,000
Hydrofluoric acid	128,000	191,000
Nitric acid	4,240,000	6,260,000

*From Reference #65.

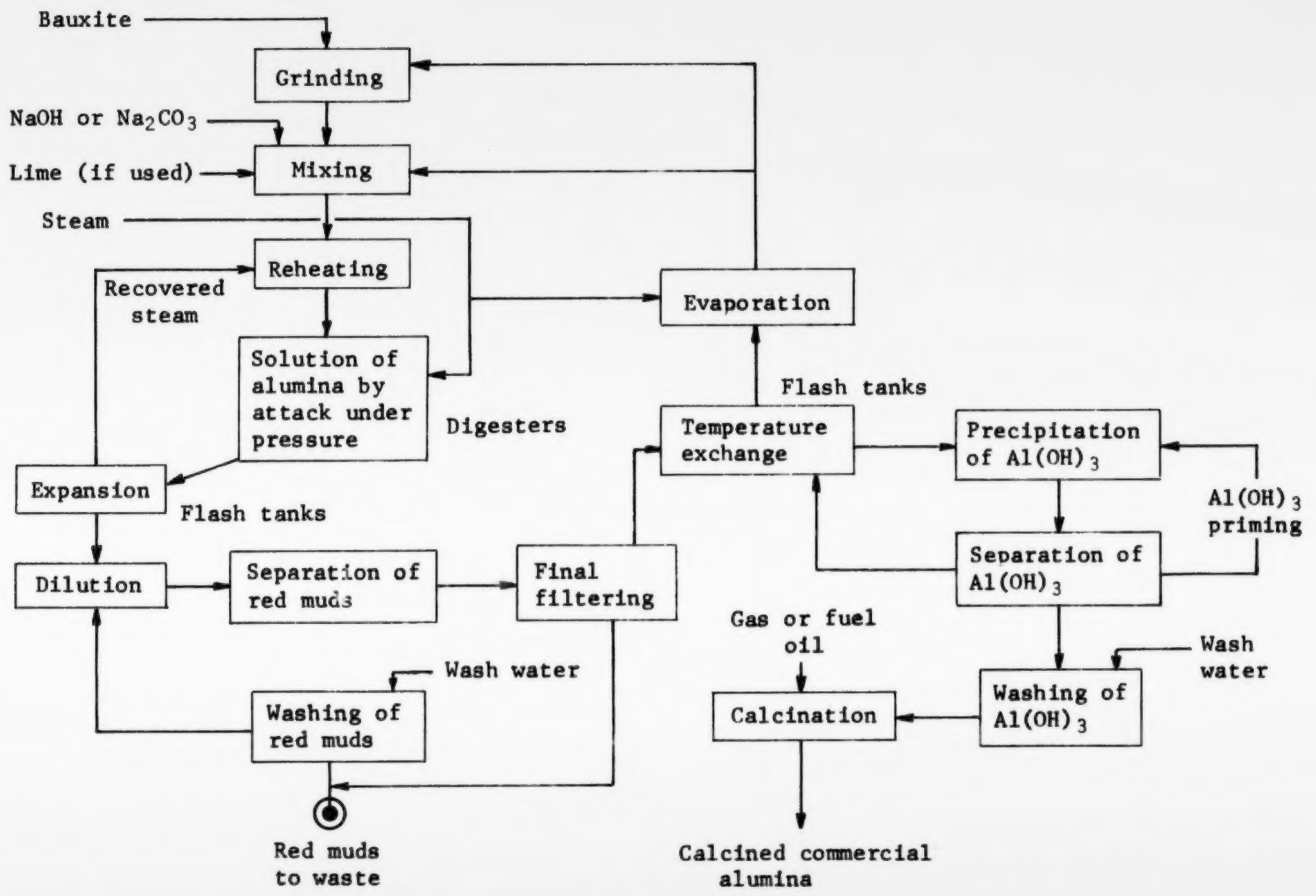
**Withheld to avoid disclosing figures for individual companies.

23, along with the production of the major chemicals within the family.

Aluminum Compounds. The basic raw material for production of aluminum compounds and metallic aluminum is alumina or aluminum oxide, which is found naturally as the mineral corundum or in the bauxite as hydrated aluminum oxide. Bauxite is the source of the major aluminum compounds, namely commercial aluminum oxide, aluminum sulfate (alum), aluminum chloride, and aluminum hydroxide. The processes using bauxite generate large quantities of wastes consisting mainly of unreacted ore.

Aluminum sulfate is used for water treatment, as well as a mild astringent and antiseptic for the skin, for dyeing, and in sizing paper. Aluminum chloride is used in the petroleum industry and in various phases of organic chemical manufacture, such as a catalyst in alkylation of paraffins and aromatic hydrocarbons by olefins, and as a catalyst in the formation of complex ketones, aldehydes, and carboxylic acid derivatives.

The production of alumina is one of the largest waste generators. The bauxite generally used contains a high percentage of iron oxide, silica, and other insolubles which are generated as solid wastes. A flowsheet of a modified Bayer process is outlined in Figure 24. Bauxite ore is slurried with a caustic solution and sent to the first of three digesters. The digester effluent contains the alumina content as sodium aluminate; it is passed through flash tanks in series. The cooled effluent, which contains about 3 percent red mud residue depending on the bauxite used, flows to filter presses or mud settlers where it is removed. The red mud is water washed to recover caustic, and usually piped to large diked lagoons for disposal. The remaining traces of mud are removed, and the filtrate passes to vacuum flash tanks. The cooled liquor goes to precipitators, where seed crystals of aluminum hydrate are used to precipitate aluminum hydrate from the solution. The coarse aluminum



Bauxite
Grinding
NaOH or Na_2CO_3
Lime (if used)
Mixing
Steam
Reheating
Recovered steam
Solution of alumina by attack under pressure
Digesters
Expansion
Flash tanks
Dilution
Separation of red muds
Final filtering
Wash water
Washing of red muds
Red muds to waste
Evaporation
Flash tanks
Temperature exchange
Precipitation of $Al(OH)_3$
$Al(OH)_3$ priming
Separation of $Al(OH)_3$
Gas or fuel oil
Calcination
Wash water
Washing of $Al(OH)_3$
Calcined commercial alumina

Figure 24. Schematic diagram for manufacture of alumina from bauxite by the Bayer Process. (From Reference #36)

hydrate crystals are washed, dewatered, and calcined to alumina.

For bauxites rich in ferric oxide the quantity of red mud generated is high, resulting in mud quantities equal to greater than the quantity of alumina produced. There are certain high-quality bauxites, however, such as those from Guiana, which generate relatively small quantities of red mud.(36)

In one method of producing alum, a chemical-grade bauxite with a low iron content is used. The waste from this process is less than that from alumina production, and consists mainly of the ore impurities silica, titania, and aluminum silicates. The mud produced when the bauxite is reacted with sulfuric acid is removed in a settling tank and is pumped to diked waste beds.

Aluminum chloride can be produced both from bauxite, usually low in both iron and silica, or directly from metallic aluminum. With aluminum as feed molten aluminum is reacted with chlorine in a furnace. When primary ingots containing few impurities are used, the aluminum is almost entirely consumed in the reaction. When the ingots are secondary aluminum, the impurities settle out as a metal dross. This dross, depending on its metallic content, is either sold for scrap or discarded.

Amonia Compounds. Second only in importance to sulfuric acid, ammonia is necessary for the manufacture of many chemicals such as calcium and sodium nitrate, ammonium sulfate, nitrate and phosphate, ammoniated superphosphates, urea, aqueous ammonia, soda ash, nitric acid, nearly all explosives, and other products. Ammonia is produced by reacting hydrogen and nitrogen in a three-to-one ratio using many variations of the original Haber process.

Ammonium nitrate and urea are both important nitrogen carriers for fertilizers and are also used for manufacture of explosives such as dynamite. Urea is used as a protein supplement feed for ruminants, and for plastics manufacture, in combination with formaldehyde and furfural. Urea production in 1967 was over 4 billion pounds, and ammonium nitrate production over 5.7 million short tons.(65)

In the production processes for both chemicals, a prilling tower is sometimes used where the chemical is solidified into spherical pellets called prills. The particles are dusted with clay or fine diatomaceous earth to minimize caking tendencies. A sludge is produced from these operations consisting of clay, small quantities of product, and clay from filters collecting unused and contaminated dust.

Ammonium chloride, a chemical used largely in dry cells, may be produced as a byproduct of the Solvay process for soda ash. The final waste liquor of the Solvay process contains calcium chloride and sodium chloride. The liquor may be evaporated to recover sodium chloride, leaving a 50 percent calcium chloride solution. This solution is saturated with ammonia and carbon dioxide in an autoclave. Calcium carbonate is precipitated and filtered off, and ammonium chloride is crystallized from solution. The calcium carbonate is a filter residue waste which is discarded.

Another process produces ammonium chloride from the reaction of ammonium sulfate and sodium chloride solutions. The ammonium chloride is recovered by crystallization. The reaction is as follows:

ammonium sulfate + sodium chloride = sodium sulfate + ammonium chloride

The byproduct sodium sulfate is separated from the ammonium chloride product and if possible sold or converted to Glauber's salt, which is sodium sulfate decahydrate, and sold. The market is poor for both sodium sulfate and Glauber's salt and much of it is wasted. Production of ammonium chloride in 1965 was 27,400 tons with only small growth predicted in the near future.(46)

Ammonia is also important to the production of nitric acid. In early years, nitric acid was produced from Chile saltpeter. Current processes are based on an oxidation reaction between ammonia and air or oxygen which generates little or no solid wastes. Its major use is in the production of nitrates in both the inorganic and organic fields and nitro derivatives of organic chemicals. Production of nitric acid in 1967 was 6,260,000 short tons.(65)

Calcium Compounds. Calcium compounds are generally derived from limestone or lime, and gypsum. For chemical usage, a rather pure ore is preferred to minimize byproduct wastes. Lime (calcium oxide) and gypsum (calcium sulfate) also appear as wastes from certain chemical processes. Lime is a cheap commodity since limestone deposits are abundant. In many cases where lime wastes are generated, it is uneconomical to attempt to remove residual impurities in the lime, and in other cases, available uses may not be able to consume all that is generated. The same is true with calcium sulfate wastes generated by such processes as hydrofluoric acid production. Gypsum can be used for making plaster wall board, but the waste gypsums generated are generally of a form or contain residual impurities that require additional processing before they can be used. It is usually cheaper to use the ore, which is readily available at a low cost.

Calcium chloride is the other compound in the waste liquor of the Solvay process. After the sodium chloride is removed, the solution is 50 percent calcium chloride. The liquor is concentrated, and the calcium chloride crystallized. Only selective quantities determined by demand are produced, however, and the rest wasted. Calcium chloride is used in deicing roads, dust control, and concrete treatment.

Iron Compounds. The most abundant industrial iron compound is ferrous sulfate (copperas). It is a waste product of the pickling process in which steel surfaces are cleaned preparatory to electroplating, tinning, galvanizing, or enameling operations, and also of the sulfuric process for production of titanium dioxide. It has been used to produce other iron compounds, and in conjunction with chlorine, is used as an iron coagulant in treatment of sewage and industrial wastes. These uses do not nearly consume all the ferrous sulfate that is produced; most is wasted.

Ferric hydroxide is produced from ferrous sulfate, and is used in production of other iron compounds such as ferric sulfate, ferric sodium oxalate, and ferric malate. Ferric oxide, a red pigment, is produced by calcining ferrous sulfate.

The demand for most iron compounds is small, with the result that production processes are also relatively small. Solid wastes from these production processes would normally be low volume and relatively easy to handle.

Magnesium Compounds. Magnesium, one of the most widely distributed elements, occurs generally as the chloride, silicate, hydrated oxide, sulfate, or carbonate in either complex or simple salts. The principal sources of these salts are sea water, certain salt wells, bitterns from sea brines, salines, dolomite, and magnesite. Solid wastes, consisting mainly of impurities in the feed material, are generated by many of the magnesium production processes used.

The production of magnesium hydroxide from sea water generates a waste sludge from a number of points in the process. In this process, sea water is pumped to hydrotreaters, and just enough dolomitic or high calcium of lime is added to precipitate carbonates which are raked off and disposed of. More dolomite is added to the treated water, which precipitates magnesium hydroxide. The magnesium hydroxide stays in suspension and is removed with the overflow. The underflow is cycled to remove all of the magnesium and the residue is wasted. The residue is a sludge consisting mainly of silicacious material and unreacted limestone.

Magnesium hydroxide is used to produce magnesium chloride by dissolving the hydroxide in 10 percent hydrocholoric acid. The solution is concentrated in direct-fired evaporators and dried. The magnesium chloride may be used in electrolytic cells to produce magnesium.

Phosphorus Compounds. Phosphate rock is the raw material used for manufacture of phosphoric acid, superphosphate, phosphorus, and other compounds. The greatest consumer of phosphorus compounds is the fertilizer industry. Impurities in the phosphate rock used in the various processes generally are removed as solid wastes.

Two important processes for phosphoric acid use phosphate rock as the feed material. These are the wet process and the furnace method, both of which generate substantial quantities of solid wastes. The wet process for phosphoric acid is shown in Figure 25. Ground phosphate rock is digested with a mixture of sulfuric acid and recycled phosphoric acid to form phosphoric acid and gypsum. From the digester, the slurry passes to tilting pan-type washing filters where phosphoric acid is removed from the gypsum filter cake. The filter cake gypsum (calcium sulfate) is ordinarily wasted by slurrying it with waste water and piping it to a settling pond. The reaction which takes place in the digester is as follows:

calcium phosphate + sulfuric acid + water = phosphoric acid +
calcium sulfate + water

The acid filtrate is evaporated to obtain the desired concentration of phosphoric acid.

In the blast furnace method for phosphoric acid as shown in Figure 26, pulverized phosphate rock is mixed with ground coke, a binder added, and the mixture compressed into briquettes. The briquettes are charged into the blast furnace along with sand and additional coke. The evolved gases contain carbon monoxide, nitrogen, and phosphorus. The clean gas is split into two portions. The first is passed through phosphorus condensers to produce elemental phosphorus. The second portion is passed into regenerative stoves where it is oxidized to phosphorus pentoxide. From the stoves, the produce is hydrated and cooled

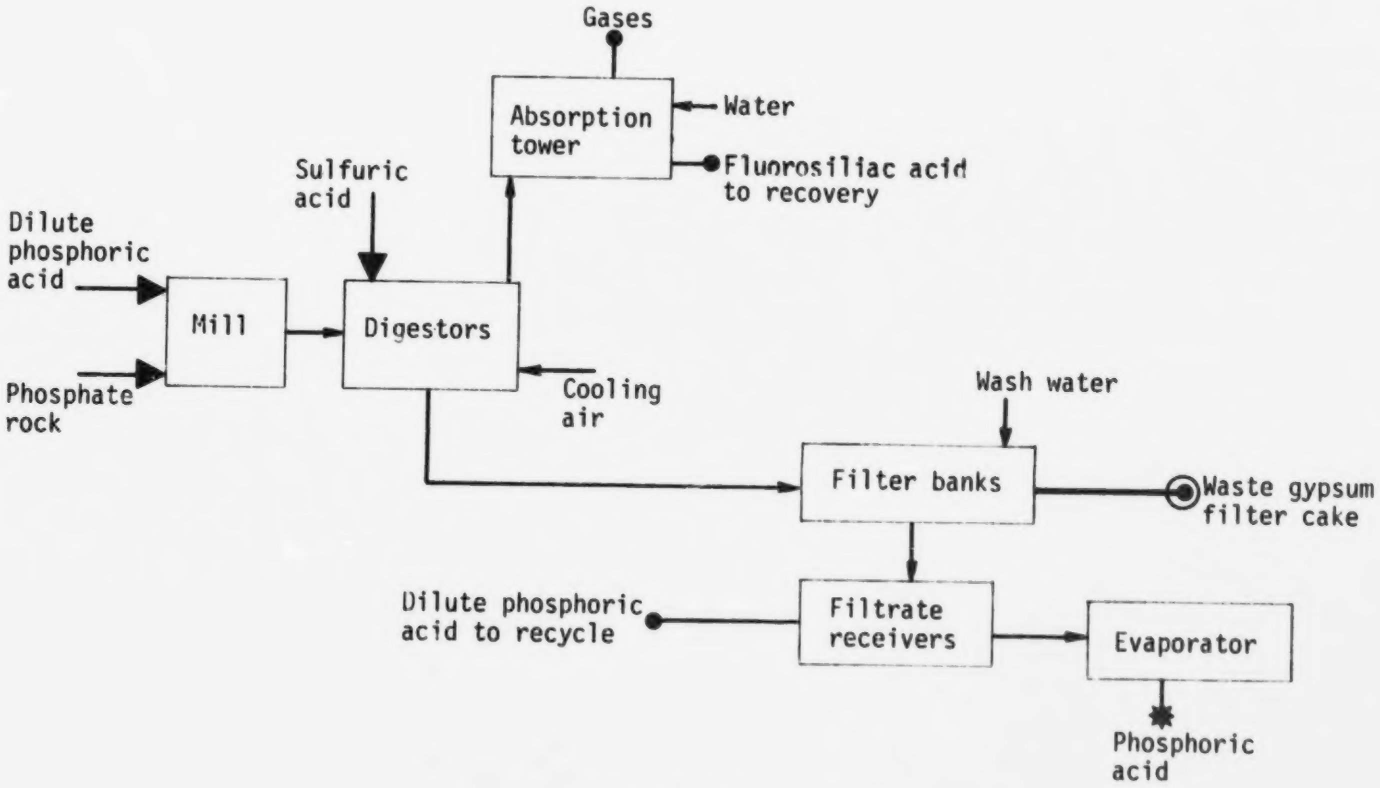

Gases
Absorption tower
Water
Fluorosiliac acid to recovery
Sulfuric acid
Dilute phosphoric acid
Mill
Digestors
Phosphate rock
Cooling air
Wash water
Filter banks
Waste gypsum filter cake
Dilute phosphoric acid to recycle
Filtrate receivers
Evaporator
Phosphoric acid

Figure 25. Schematic diagram for manufacture of phosphoric acid from phosphate rock by the wet process. (From Reference #26)

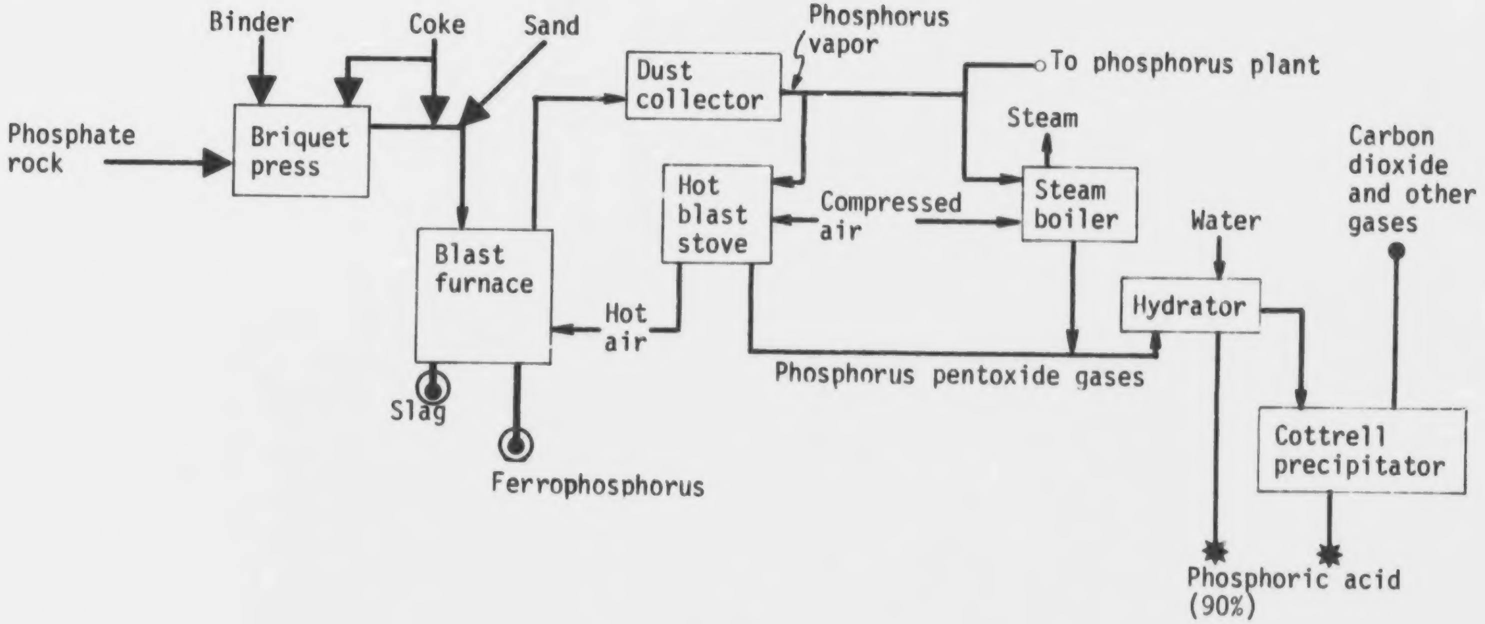

Binder
Coke
Sand
Phosphate rock
Briquet press
Blast furnace
Slag
Ferrophosphorus
Hot air
Dust collector
Phosphorus vapor
Hot blast stove
Compressed air
To phosphorus plant
Steam
Steam boiler
Phosphorus pentoxide gases
Water
Hydrator
Carbon dioxide and other gases
Cottrell precipitator
Phosphoric acid (90%)
Phosphoric acid

Figure 26. Schematic diagram for manufacture of phosphoric acid and phosphorus from phosphate rock by blast furnace. (From Reference #26)

TABLE 24

PRODUCTION OF SODIUM PHOSPHATES-1967*

Sodium Phosphate	Production 1,000 Short tons
Monobasic (100%)	17.4
Dibasic (100%)	22.6
Tribasic (100%)	61.7
Tetrabasic (100%)	109.0
Meta (100%)	88.1
Acid pyro (100%)	25.2
Tripoly (100%)	1,050.0

*From Reference #65.

and passed through Cottrell precipitators for removal of entrained phosphoric acid The condensed acid is purified by treatment with hydrogen sulfide, followed by filtration.

About 95 percent of the phosphorus in the rock raw material is volatilized, and the remaining phosphorus, along with the impurities in the rock consisting chiefly of calcium silicate and iron compounds, leave the blast furnace as solid wastes. During the time the rock mixture is in the blast furnace, the furnace is tapped once an hour to remove the calcium silicate as a slag. Every 12 hours the furnace is tapped to remove the iron impurities as a heavier ferrophosphorus. The slag can be used for its calcium content in glass manufacture, liming of soil, or as roadbed ballast. The ferrophosphorus can be sold as a phosphorus additive to steel.

Elemental phosphorus is also produced using an electric furnace in place of the blast furnace. The same solid wastes are generated from this furnace. The phosphorus can then be used for production of phosphoric acid in a process generating little or no solid waste. In 1967, 1.1 million short tons of phosphoric acid were produced from phosphorus, and 4.0 million short tons from phosphate rock.(65)

Sodium phosphates are the largest tonnage chemicals based on pure phosphoric acid. Of these, disodium phosphate, is the base of all the other phosphates. The most important use of sodium phosphates is in detergent manufacture, which consumes 80 percent of the production. Production of the important sodium phosphates is listed in Table 24.

The production process for manufacture of disodium phosphate and trisodium phosphate is shown in Figure 27. A sodium carbonate (soda ash) solution and phosphoric acid are added to a mixing tank under conditions promoting high carbon dioxide liberation. The solution is boiled with steam until all of

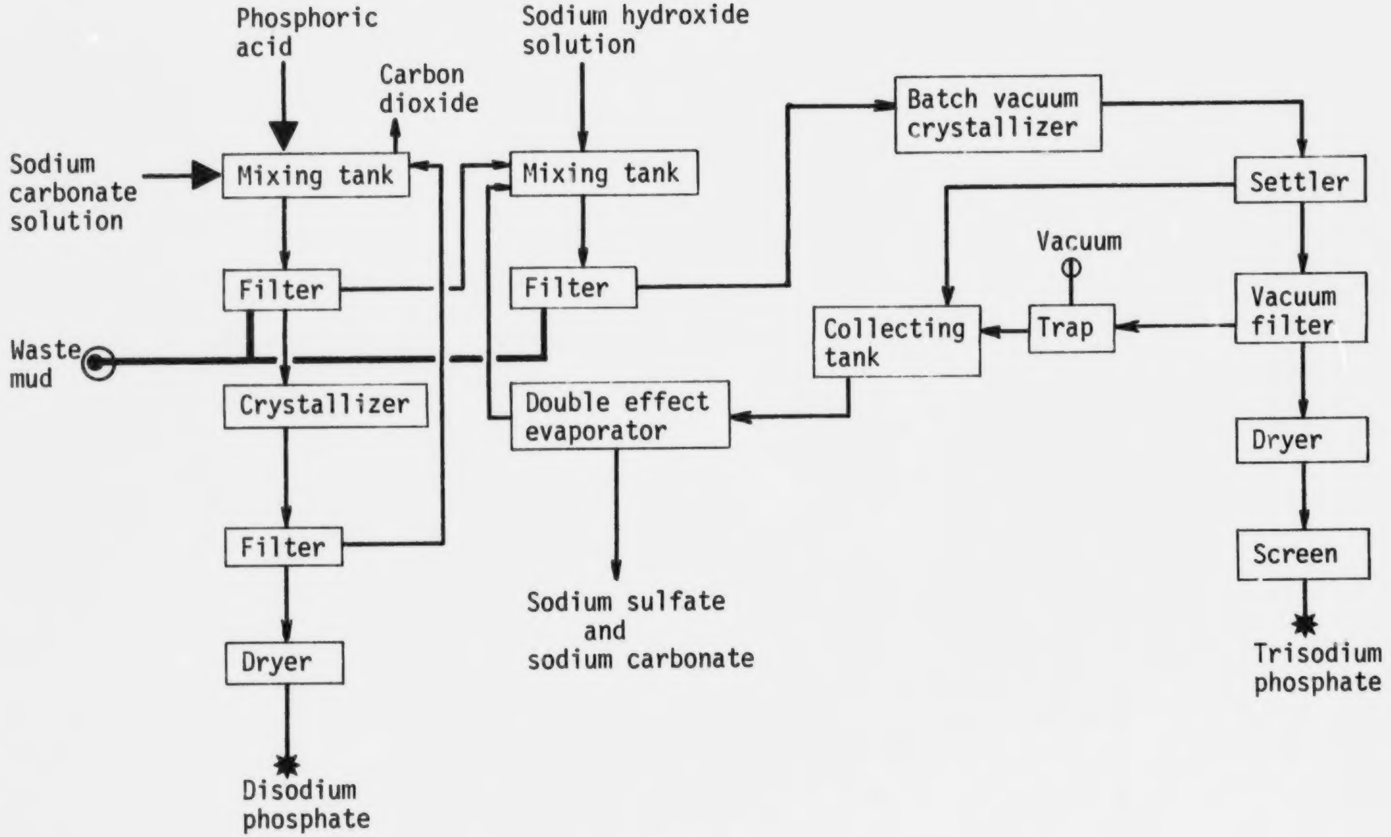

Phosphoric acid
Sodium carbonate solution
Carbon dioxide
Mixing tank
Filter
Waste mud
Crystallizer
Filter
Dryer
Disodium phosphate
Sodium hydroxide solution
Mixing tank
Filter
Double effect evaporator
Sodium sulfate and sodium carbonate
Batch vacuum crystallizer
Settler
Vacuum
Collecting tank
Trap
Vacuum filter
Dryer
Screen
Trisodium phosphate

Figure 27. Schematic diagram for manufacture of disodium phosphate and trisodium phosphate from phosphoric acid and sodium carbonate. (From Reference #26)

the carbon dioxide has been driven off. The resulting disodium phosphate solution is filtered hot and the filtrate split into two portions, one for diosdium phosphate and the other for trisodium phosphate manufacture. The filter residue is a white waste mud consisting of silica, iron, and aluminum phosphate.

One part of the solution is cooled in a crystallizer to yield crystals of disodium phosphate which are filtered from the mother liquor and dried. A 50 percent sodium hydroxide (caustic soda) solution is added to the other part of the solution. The hot solution is filtered and the filtrate crystallized and dried to yield trisodium phosphate crystals. The filter residue is again a white waste mud. The mother liquor is sent to a double-effect evaporator, concentrated, and sent back to the mixing tanks for reprocessing. Sodium sulfate and sodium carbonate are discharged from the bottom of the evaporator. The sodium sulfate (salt cake) may be sold for sulfate pulping, detergent, or glass manufacture. The sodium carbonate may be recycled back to the original mixing tank. Manufacture of the other sodium phosphates is based on these two phosphates.

Potassium Compounds. Potassium salts, chiefly potassium chloride and potassium sulfate, are basic chemicals for production of potassium compounds. Potassium chloride is obtained from deep deposits of sylvinite or langbenite. Another important source of potassium chloride is Searles Lake at Trona, California, a deposit of solid sodium salts permeated by a saturated complex brine. The brine is processed to obtain potassium chloride along with borax and other saline products.

Potassium chloride is obtained from sylvinite by two major processes: fractional crystallization or flotation. Sylvinite ore is approximately 43 percent potassium chloride and 57 percent sodium chloride. Both processes operate to remove the potassium chloride from the sodium chloride. In the process, sodium chloride is removed as a wet cake and discarded.

Potassium sulfate is produced by treatment of potassium chloride with sulfuric acid or by fractional crystallization of kainite. Potassium chloride and potassium sulfate are used as a source of potassium salts in fertilizers.

Other important potassium chemicals are potassium hydroxide, produced from electrolysis of potassium chloride solution; production of potassium carbonate from potassium hydroxide; and potassium nitrate produced from sodium nitrate and solid potassium chloride.

Sodium Compounds. Most of the sodium compounds are derived directly or indirectly from ordinary salt, sodium chloride. Salt is a mineral and must be mined from the earth or the sea and refined. It is usually obtained in three different ways: solar evaporation of sea water and salt-lake brines, mining of rock salt, and from well brines.

In the chemical process using brines, the sodium chloride must be removed from the brine impurities. This is usually accomplished by adding dilute solutions of caustic soda and soda ash to remove the calcium, magnesium, and iron compounds. These impurities are precipitated and settled out of solution as a slurry. The slurry is sometimes sent to settling ponds where the waste solids settle out.

The two most important sodium compounds, sodium carbonate (soda ash) and sodium hydroxide (caustic soda) are alkalies and were discussed earlier along with sodium bicarbonate. Sodium phosphates were also discussed earlier.

Sodium sulfate or salt cake is also a naturally occurring sodium salt used as a raw material for other sodium chemicals. Glauber's salt, used in large quantities by the kraft paper industry, is a form of salt cake. It is also a byproduct of some chemical processes. It is produced directly from natural brines, but also is produced from salt and sulfuric acid with additional production of hydrochloric acid. The process is shown in Figure 28. Salt and sulfuric acid are charged to a furnace (MANNHEIM furnace) and slowly heated to a temperature just below fusion. Hydrogen chloride gas is evolved and sent to hydrochloric acid recovery. Salt cake (crude sodium sulfate) is obtained from the periphery of the furnace. To obtain Glauber's salt, part of the salt cake is dissolved in hot water and neutralized with soda ash and lime. The neutralization precipitates iron and alumina which settle to the tank bottom. The mud is filtered from the solution and the waste filter cake discarded. The filtrate is crystallized to obtain Glauber's salt.

Sodium chromate and dichromate are produced by calcining a mixture of chromite ore, limestone, and soda ash. Solid wastes generated from this process are the impurities in the limestone and chromite ore used.

Sulfur Compounds. Sulfuric acid is considered to be one of the most important chemicals in the industrial chemical industry. It is a strong and relatively cheap acid which is used by countless industries, but is not usually present in finished products. Production is by two main processes, the Contact process and the Chamber process; the Contact process is the primary producer. Both processes use sulfur dioxide to produce sulfur trioxide which is converted to sulfuric acid. Sulfur dioxide is obtained from burning elemental sulfur which is greater than 99.5 percent pure. This method accounts for more than 70 percent of all U.S. acid production. The predominant sources of elemental sulfur are mines on the Gulf Coast of Louisiana, Texas, and Mexico. The recovery of sulfur from sour natural and refinery gas is a relatively small source. Frasch-process sulfur contains 0.01 percent to 0.02 percent ash, and gas-recovered sulfur only 0.001 to 0.003 percent ash.(55)

When the elemental sulfur is burned, a portion of the ash or inert materials remains as a solid waste. The ash is only a small percentage of the elemental

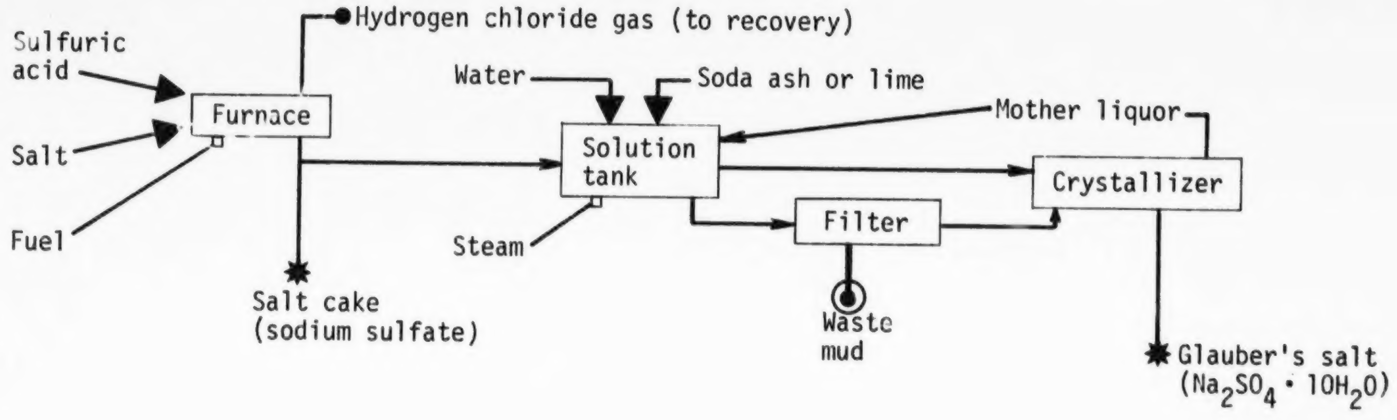

Hydrogen chloride gas (to recovery)
Sulfuric acid
Salt
Fuel
Furnace
Water
Soda ash or lime
Mother liquor
Solution tank
Steam
Crystallizer
Filter
Salt cake (sodium sulfate)
Waste mud
Glauber's salt ($Na_2SO_4 \cdot 10H_2O$)

Figure 28. Schematic diagram for manufacture of Glauber's salt from salt and sulfuric acid. (From Reference #26)

sulfur used and amounts to only very small quantities of waste at individual plants. The balance of the process, however, is relatively clean.

Sulfur dioxide, an intermediate in the production of sulfuric acid, is also used as a bleaching agent, a food preservative, in sulfite pulp manufacture, and in the production of many other chemicals. Both sulfuric acid and sulfur dioxide are the main chemicals used for sulfate formation and for sulfonation to obtain the many chemical compounds containing sulfur. Many sulfates have been discussed in previous sections.

Hydrofluoric Acid. The important inorganic acids, phosphoric, sulfuric, and nitric, were discussed previously. Hydrofluoric acid, a major inorganic acid whose production generates significant quantities of solid waste, should also be included in this discussion. Hydrofluric acid (HF) is important to manufacture of fluorocarbons and aluminum; the latter consumes 84 percent of the HF produced. In 1967, production of HF was 190,000 short tons with a growth rate forecast at 5 percent through 1971.(46,65)

The major process for production of hydrofluric acid is shown in Figure 29. Acid-grade fluorspar and sulfuric acid are continuously charged to a reactor fired by fuel gas. The reaction is as follows:

calcium fluoride + sulfuric acid = hydrofluoric acid +
calcium sulfate

The calcium sulfate (gypsum) is a residue containing only 1 percent or less of unreacted fluorspar, and is continuously discharged at weights equal to 1.75 times that of the spar charge. This waste is usually slurried and piped out to waste beds where the solids settle out and eventually dry to a hard scaly mass. The gas from the reaction is absorbed in water and concentrated by distillation to yield the various grades of aqueous and anhydrous hydrofluoric acid.

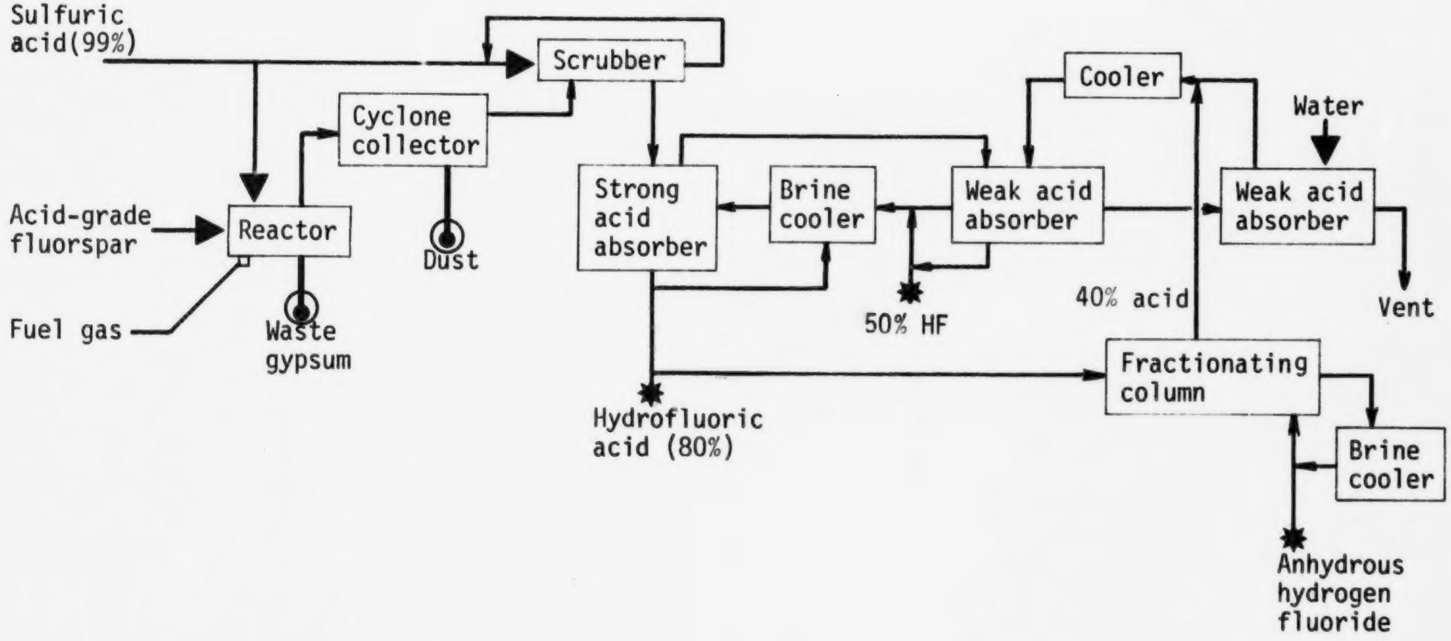

Sulfuric acid(99%)
Scrubber
Cyclone collector
Acid-grade fluorspar
Reactor
Fuel gas
Waste gypsum
Dust
Strong acid absorber
Brine cooler
Weak acid absorber
Cooler
Water
Weak acid absorber
Vent
50% HF
40% acid
Fractionating column
Hydrofluoric acid (80%)
Brine cooler
Anhydrous hydrogen fluoride

Figure 29. Schematic diagram for manufacture of hydrofluoric acid from fluorspar and sulfuric acid. (From Reference #26)

SECTION SIX: MANAGEMENT OF SOLID WASTES

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SECTION SIX: MANAGEMENT OF SOLID WASTES

Management of solid wastes includes waste storage, collection, transportation, preparation, and disposal. This section provides a brief description of the methods and equipment used for management systems in the industrial chemical industry, and discusses their suitability to the various waste types, along with an analysis of system alternatives.

Storage, Collection, and Transporation

Non-Process Waste. The systems used by industrial chemical plants for the storage, collection, and transportation of plant non-process waste are the same as those used by other industrial plants and commercial establishments. Containers for waste storage are located throughout the plant near generating areas. The containers consist of a variety of receptacles such as boxes and barrels, or those designed for solid waste storage, such as dumpster boxes or concrete bins. The majority of plants salvage metal waste and provide separate containers for metal and trash. Normally the wastes are collected from the storage facilities by truck.

Systems vary for non-process waste collection and transportation to final disposal. A plant may use trucks to pick up solid waste from each container and haul it directly to disposal, or the smaller containers may be emptied into larger ones and then hauled to disposal. In some cases one or two large containers, sometimes large stationary compactors, are used to receive all the wastes of the plant, which are periodically hauled to disposal. Many plants have instituted a completely containerized system where large specially-designed containers are located throughout the plant. They are picked up periodically by trucks equipped to haul the entire container to disposal, after which the container is returned to its location. The system chosen by a plant depends

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in part on the quantities of trash to be handled and on costs.

Process Wastes. Normally process wastes are handled separately from non-process wastes. Storage facilities for process wastes consist of a variety of bins, barrels, fiber drums, tanks, and luggers or dumpsters, as well as ponds, tank trucks, and railroad cars; they are sometimes piled casually on the ground.

Heavy sludges that cannot be pumped are generally stored as described above. Sludges stored in bins, or stored casually, must be removed and desposited in trucks for transportation to disposal. If they are contained in fiber drums, the drum is usually disposed of along with the sludge. Luggers and dumpsters are metal containers which can be lifted and their contents dumped into a truck, or the container carried to the disposal area and dumped. Sludges stored in railroad cars are generally off-quality product which is stored longer than usual to allow time for possible marketing opportunities. In many cases, the railroads will haul sludges stored in their cars to land which they own. Most filter residues would be handled in the same manner as sludges.

Tars and aqueous sludges that can be pumped are stored in barrels, tanks, ponds, tank trucks, and railroad cars. Barrels are either emptied at the disposal site or in landfills; sometimes, they are buried along with the waste. Tanks are often used both at the point of waste generation and at the disposal site. They are used with tar incinerators not only to provide storage but also to provide an opportunity to mix various wastes to form a desirable blend for burning. Some tanks are heated to liquify tars that would solidify at normal temperatures. Similarly, tanks are often equipped with agitating means to prevent settling of suspended solids and to assist in preventing tars from solidifying. When the waste is stored in ponds, it is either pumped by pipeline directly from the pond to disposal or into tank trucks. As with sludge, railroad tank cars sometimes are used for off-quality tar wastes.

Flyash is either stored in bins or hoppers at the powerhouse or pumped out to ponds or lagoons. Trucks, or in some cases rail cars, pick up the flyash from hoppers and transport it to disposal. Depending on the capacity of the pond or lagoon, the flyash either remains in the basin or is dredged out and hauled to disposal.

Transportation equipment used for hauling process solid waste from storage to disposal consists of open dump style trucks, tank trucks, railroad cars, barges, and pipelines. As previously mentioned, some tank trucks must be capable of heating and agitating the waste to prevent solidification. Barges are used to transport some waste to ocean disposal. In most cases where pipelines are used, the waste is not stored, since the pipeline carries the waste directly from the generating process to disposal in a continuous operation.

Disposal

Non-Process Waste. Disposal methods for non-process wastes as used by the chemical industry are essentially the same as those used for municipal and commercial refuse. The methods are all variations of land disposal or incineration. No plants were found that employed composting, and the few governmentally operated composting plants in the country receive an insignificant amount of non-process waste from industrial chemical plants.

Land disposal methods fall into the categories of burning dumps, open dumps, landfills, and sanitary landfills. Dumps exist where the solid wastes are deposited on the ground and left in the open for considerable period of time. In some cases the dumps are deliberately fired to reduce waste volume. This practice is increasingly running afoul of state regulations. In a landfill, the solid wastes are periodically covered with fill material. A sanitary landfill is a particular type of landfill which must meet certain criteria--i.e. (1) It must be operated without creating a nuisance or a hazard to public health or safety; (2) The solid wastes must be confined to the smallest practical area, reduced to the smallest practical volume, and covered with a prescribed layer of earth at the conclusion of each day's operation; and (3) Ground water contamination from leaching must be controlled. This is the most desirable form of land disposal. The disposal of refuse by landfilling has been studied extensively by a number of authors.(17,19,50)

Incineration of non-process waste is also accomplished by a number of methods, including open burning, burning in tepees, and incineration in single and multiple chamber incinerators with or without stack air pollution control equipment. Incineration of refuse has been described in detail in a number of publications.(16,42,62)

In the past, many chemical plants disposed of non-process waste by open burning or in tepee burners, which are large tepee-shaped structures serving to protect the burning material from blowing about, but having little beneficial effect on reducing air pollution. Air pollution regulations have virtually eliminated these two waste disposal forms at chemical plants, and they have been replaced by incineration, landfilling, or hauling waste to nearby private or municipal facilities.

Most landfills operated by industrial chemical plants do not meet all the criteria to be considered sanitary landfills. They are often not covered each day, but this is usually not as critical as with municipal refuse since the small amount of garbage in the plant trash is not as likely to attract rodents. In addition, most are not properly located or sealed to prevent possible ground water pollution. These same conditions have been reported for private and municipal landfills.(43) In addition, plant landfill operators may often experience difficulty in providing proper compaction of the waste, thereby leaving voids which may cause uneven settlement. The difficulty stems from the large quantities of discarded cardboard boxes, crates, and fiber drums which are unusually hard to compact.

Process Waste. Disposal of process solid wastes is generally accomplished by incineration, land disposal, settling in lagoons or ponds, and ocean dumping. This section presents a brief description of each method.

Conventional Incineration. Many types of conventional incinerators designed for combustion of refuse have been adapted for disposal of ehcmical process solid wastes. The incinerators have been used for solid chemicals, sludges, filter residues, off-quality product, and tars. The waste must contain a sufficient percentage of combustible material and be physically compatible with the incineration equipment. For example, certain wastes such as sludges may be dried from 80 percent moisture to 15 percent moisture before incineration.

Some incinerators have been designed to burn both process and non-process wastes together. Figure 30 shows a typical incinerator equipped to incinerate refuse, solid chemicals, heavy sludges, and tars. Plant refuse is dumped into a storage pit and deposited by a bucket crane into a receiving hopper. The waste is conveyed to a rotary kiln where primary combustion occurs. Other units may have manual charging and either a grate furnace or a rotary hearth furnace instead of the rotary kiln. At the end of the kiln, the ash is dropped to a hopper and the combustion gases pass through a secondary combustion zone, possible spray cooling and air pollution control equipment, and then to the stack.

Tars or other combustible liquids are pumped to a burner and fired in the primary combustion chamber of the furnace. Low ash content tars are most desirable for this type of incineration, since the tars are burned in suspension

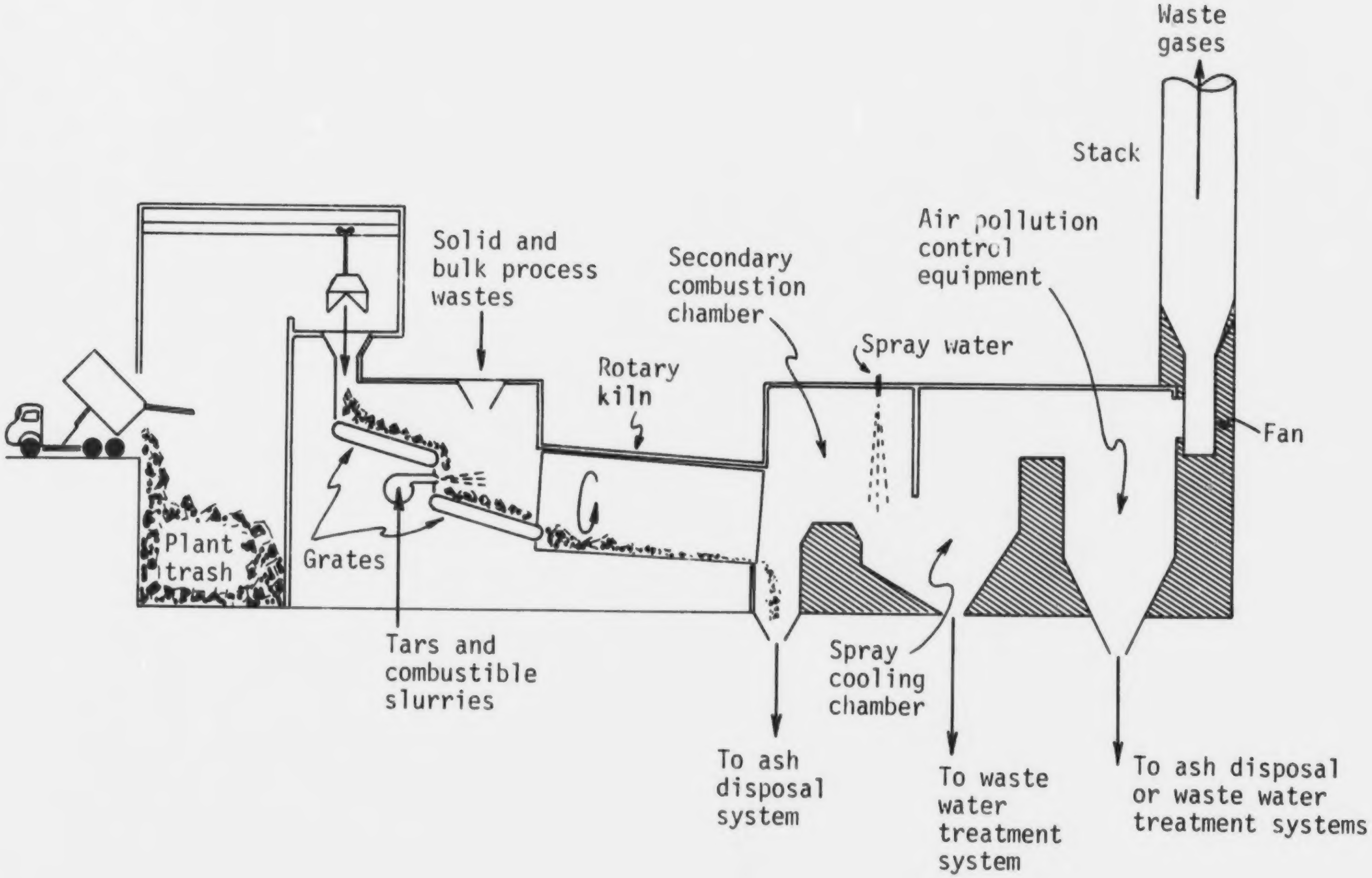
Waste gases
Stack
Air pollution control equipment
Solid and bulk process wastes
Secondary combustion chamber
Spray water
Rotary kiln
Fan
Plant trash
Grates
Tars and combustible slurries
Spray cooling chamber
To ash disposal system
To waste water treatment system
To ash disposal or waste water treatment systems

Figure 30. Schematic diagram of combined process and non-process waste incinerator.

and any ash produced could cause air pollution problems. Solid chemicals and sludges are also charged to the primary combustion chamber. In many cases they are contained in fiber drums, and the whole package is charged as a unit. Shredding of the waste prior to incineration is normally not done.

Temperatures in these units will range from 1400 F to 2000 F. It is desirable to maintain temperatures at the higher end of this range to insure complete breakdown of organic materials. Generally, incinerators of this type cannot handle materials which will produce corrosive combustion products (e.g., HCl from the destruction of chlorine-containing organics), unless special materials of construction are used and precautions are taken to scrub such reactive materials from the exhaust gases.

Tar Incinerators. Tar incinerators are specially designed for burning tar wastes or other liquids such as acid wastes, contaminated solvents, and slurries such as waste water sludge. The design of the incinerator depends to a large extent on the combustion products of the tar to be burned. Tars vary considerably in chemical composition, and thus in combustion characteristics and products.

The four basic types of tar burners are shown in Figure 31. The primary combustion zone and firing mechanism may vary (for some units) from those shown, but the basic sequence of operation is essentially the same.

Units 1 through 4 provide for progressively greater control of combustion. Burner #1 is usually used to incinerate highly volatile waste tars with negligible ash content and no gaseous pollutant combustion products. The combustion flame burns completely in the open, and when properly operated is smokeless. Burner #2 provides for greater control of the combustion process by enclosing the combustion zone and providing a stack for discharge of gases.

A secondary mixing and combustion chamber and a settling chamber, as well

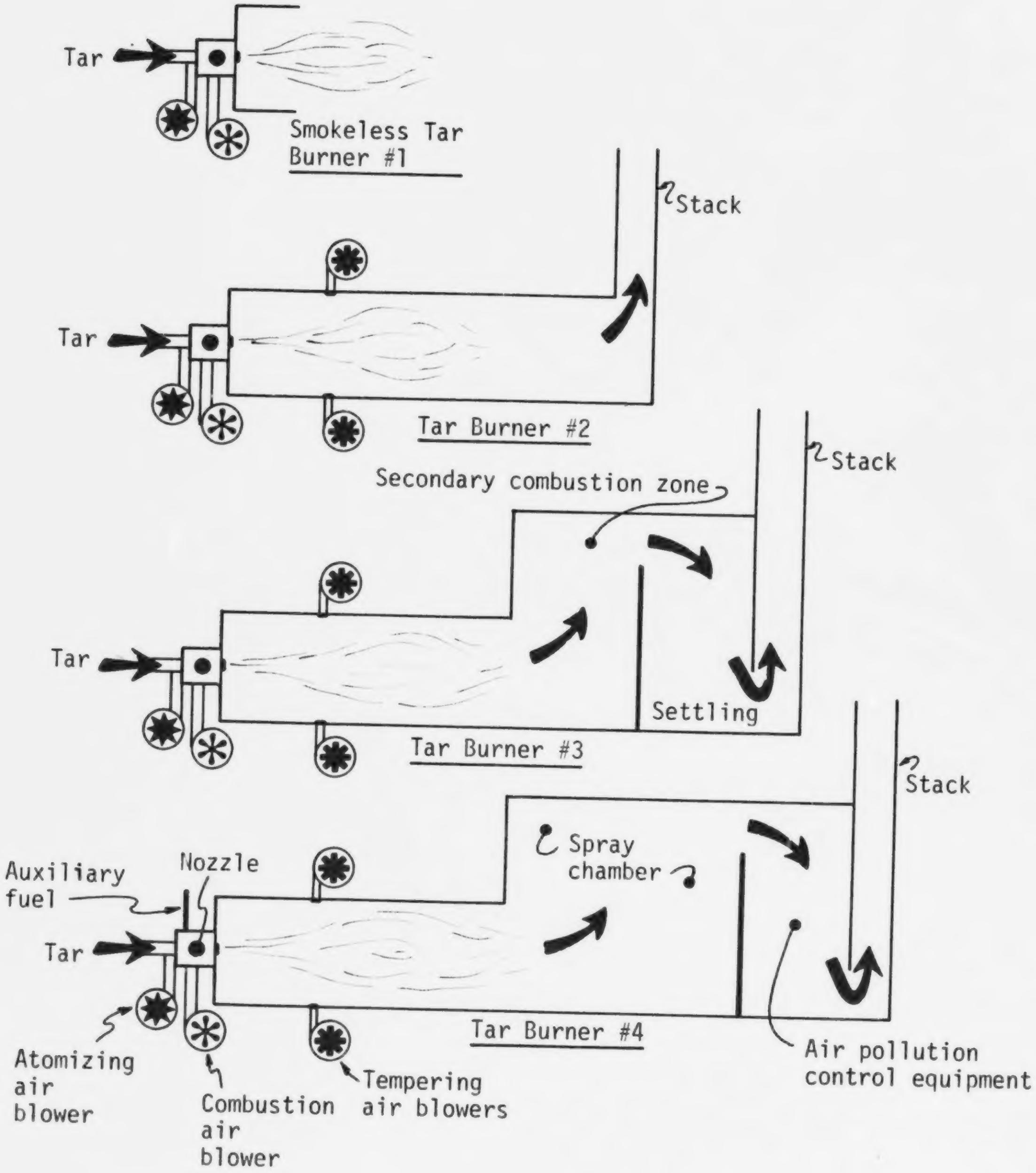
Tar
Smokeless Tar Burner #1
Stack
Tar
Tar Burner #2
Stack
Secondary combustion zone
Tar
Settling
Tar Burner #3
Stack
Spray chamber
Auxiliary fuel
Nozzle
Tar
Tar Burner #4
Atomizing air blower
Combustion air blower
Tempering air blowers
Air pollution control equipment

Figure 31. Schematic diagrams of tar burners.

as a higher stack, are provided in burner #3. This burner would be used for tars which might generate small quantities of particulate matter on combustion. The settling chamber would remove some particulate, and the taller stack would assist in dispersion of particulates to the atmosphere.

For tars which on combustion generate high quantities of particulates or noxious gases, burner #4 is required. These tars require a highly refined burner system and air pollution control equipment sufficient to control pollutant emissions.

Types of tars which contain halogens require equipment for incineration similar to that of burner #4. Burning this material might generate the elemental halogen or the acid gas. Tar incinerators for this material are usually designed to generate the acid gas which is then scrubbed.

An example of tars containing halogens are those from the production of chlorinated organic chemicals. Large volumes of this waste, containing some residual chlorine, are generated. The chlorine atom in the waste is not combustible, but carbon and hydrogen are. Hydrogen will react with chlorine to form the acid gas HCl, but unless there is sufficient hydrogen to combine with all the chlorine, unreacted chlorine will be released to the atmosphere in its elemental form.

In addition, with low combustion temperatures, intermediates such as methyl chloride and phosgene may be formed and released. Elemental chlorine is difficult to scrub from a gas stream and requires special caustic scrubbing solutions. Incinerator designs for this tar provide for excess hydrogen through auxiliary fuel such as natural gas or steam at high temperatures. The acid gas can then be scrubbed from the exhaust using water in either low-energy-packed bed-type systems or high-energy venturi scrubbers. The scrubbing water becomes a weak HCl acid solution. It may either be reclaimed to produce various grades

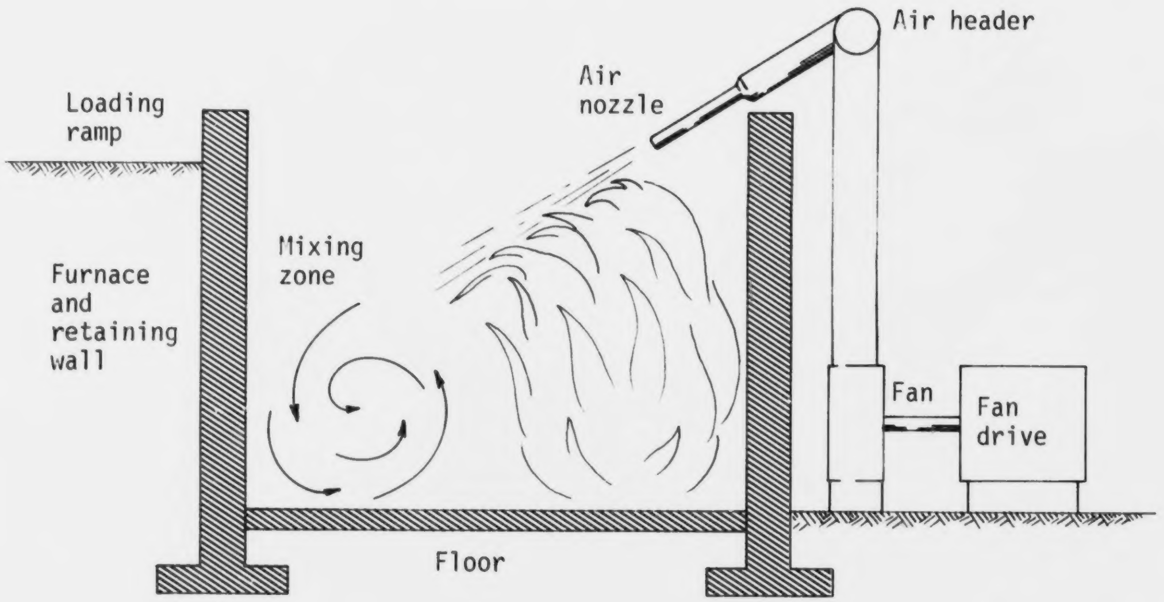
Air header
Air nozzle
Loading ramp
Mixing zone
Furnace and retaining wall
Fan
Fan drive
Floor

Figure 32. Schematic diagram of open pit incinerator.

of hydrochloric acid or neutralized and sent to receiving waters, the usual practice.

Tar burners operate over a wide range of temperatures from about 1800 F to as high as 3500 F. At these high temperatures, and with the possible presence of acid gases, corrosion and damage to fire brick can be a serious problem.

Tar burners can handle a variety of tars, slurries, gases, and liquids including wastes with a high percentage of noncombustible matter or highly aqueous wastes. Because the wastes are fired through a nozzle, there are limitations of particle sizes in slurries and on certain characteristics of tar wastes to prevent clogging of the nozzle. The waste tars which cannot be incinerated must be treated by an alternate method. These practices usually result in inadequate disposal.

Other Incineration Methods. An additional type of incinerator used to handle both process and non-process waste is the open pit incinerator. It is presently used to incinerate trash, tars, and sludges. The incinerator is a box-shaped pit with no top, permitting maximum radiation of the flame to the sky. Depth of the pit ranges from 10 to 30 feet. Normally, all air is supplied from an overfire position to produce maximum turbulence and recirculation of the combustion gases.

A typical open pit incinerator is shown in Figure 32. For solids with high calorific value and solids that tend to melt, the open pit incinerator combustion rate and performance have been reported as high, particularly for wastes with less than 1 or 2 percent ash. However, such an incinerator provides little control over emission of particulate matter or noxious gases which are generated by combustion of some wastes.

Fluidized, granular-bed incinerators have been used successfully with volatile sludges which can be pumped or moved on a screw conveyor. These incinerators cannot, however, handle sludges containing large particles, due to bed plugging.

Waste Heat Recovery. Few industrial chemical plants recover waste heat from incineration of solid wastes. Although in most cases a plant could use the heat energy for production of steam, the design, operation, and maintenance of a waste heat boiler is wrought with problems. Two boiler design problems which must be given special consideration when firing solid wastes are fouling of heating surfaces and potential corrosion. For chemical plant wastes, these design considerations are even more critical due to the diffuse nature of wastes incinerated and the increased possibility of acid corrosion. Despite these problems and the expense involved, a few waste heat boilers do operate successfully at chemical plants for both process and non-process waste incinerators.

A more common method of utilizing the heat from combustion of wastes is to fire the waste as a supplementary fuel into the main plant boilers. A number of plants were found to be using this disposal method for certain tars, solvents, and other organic liquids. Boilers were found with a waste fuel burning capability of up to 20 percent of capacity. Little information is available, however, on the design, operation, or applicability of this procedure to specific waste types.

Land Disposal. Land disposal of solid wastes by chemical plants consists of either dumping the waste in piles on the ground or burying it. All the major types of process solid wastes are sometimes disposed of by this method, including sludges, tars, off-quality product, filter residues, and flyash.

Wastes dumped on the ground are principally dry chemicals, filter residues, and heavy sludges. They are generally inert and insoluble inorganic chemicals which do not generate odors on decomposition or pollute surface and ground waters through leaching of pollutants. Other effects of some solid wastes (such as emission of noxious gases, dusting, or esthetic problems) may prevent disposal by this method. A large percentage of the solid wastes dumped on the ground are sludges dredged from settling ponds or lagoons.

The second method of land disposal consists of direct burial or covering the waste with earth. Generally, the plant area for land disposal of process waste is separate from any landfills for non-process waste. The same problems associated with landfilling refuse, however, occur when landfilling chemical wastes. Pollution of surface or ground water is possible if proper precautions are not taken, especially with readily soluble wastes. Decomposition of the wastes may produce other chemical and biochemical products or gases which can also affect water or air quality.

Very little information is available on the mechanism and rate of decomposition of most chemical wastes when landfilled. The principal soil transformation process is biological decomposition. Microorganisms are capable of biological oxidation or reduction of both inorganic and organic chemicals, resulting in a broad array of chemical and biochemical products.

It has been reported that most aliphatic hydrocarbons are rapidly decomposed in soil. Hydrocarbons which are unsaturated, branched, and of high molecular weight are generally more susceptible to degradation than their saturated, unbranched, low-molecular-weight analogues. Aromatic materials, on the other hand, are generally considered quite resistant to microbial degradation in soil and water, and carbon in aromatic forms constitutes a major portion of the relatively stable soil organic fraction. Once the aromatic ring is cleaved, however, the resulting straight-chain hydrocarbons are subject to relatively rapid degradation and oxidation to carbon dioxide and water.(57)

The rate, extent and direction of microbial transformations in soil, however, are commonly dependent upon the type and quantity of available energy sources, availability of essential nutrients, degree of aeration, temperature, moisture, pH, and the presence of toxic substances. Large variations in these factors exist in chemical landfills depending on the procedures used and the chemical wastes disposed. In some cases, when disposing of solid chemicals or sludges, the material will be mixed with the soil. In other cases no mixing is practiced, resulting in large slugs of chemical wastes in the fill. Waste tars or liquids contained in drums are often buried, and when the barrels corrode, the contents leach into the landfill. More information is necessary on the effect of these practices and on the fate of landfilled chemical wastes before land disposal procedures can be formulated which adequately protect the environment.

Lagoons and Ponds. Lagoons or ponds are both natural water bodies or man-made water bodies constructed either by digging out a depression in the earth or by erecting dikes. "Lagoons" normally refer to basins where the overflow easily passes into receiving waters, and "ponds" are usually those basins with no overflow. The liquid portion becomes permanently entrapped in the pond and is reduced only through evaporation. Lagoons are better suited for wastes with low solids content and ponds for those with high solids content. Lagoons are used for clarification of both chemical plant process waters and waste waters, and along with ponds are used for slurries and solids deliberately slurried to enable transport by pipeline. As the basins fill, they are either cleaned and the solids removed and discarded, or the solids are left to dry and new basins are constructed. If the liquid portion of the waste can contaminate underground water, special precautions must be used to seal the lagoon or pond bottom to prevent leakage.

Lagoons sometimes cover many acres and receive thousand of tons of solid wastes annually. Where a high degree of solids clarification is desired, lagoons may be arranged in series with each successive lagoon providing treatment until the desired water quality is reached. Under some conditions aerobic or possibly anaerobic decomposition of wastes may occur in the lagoons, thereby providing further treatment.

Ocean Disposal. Although the mail questionnaire turned up only a reltively small quantity of chemical wastes disposed to the ocean, ocean disposal of solid wastes is known to be a well-established practice. Specific areas in the ocean have been set aside for solid waste disposal, some specifically for chemical wastes. Virtually all types of process wastes are disposed of in the ocean except possibly flyash. Solid wastes for ocean disposal are generally loaded aboard a barge and hauled to disposal areas at sea. The wastes are transported and disposed in bulk or in barrels. Bulk wastes are either dumped directly or discharged underwater and allowed to mix with the barge wake. Barreled waste is pushed overboard and usually sinks, and those that float are shot full of holes.

A preliminary report on ocean disposal off the West Coast indicates that such industrial chemicals as acids, sludges, solvents, spent caustics, waste liquors, and plating solutions are disposed of at sea.(29) It was estimated that 1,254,000 barrels of these chemical wastes were discharged in 1968 off the Pacific coast at a cost of $153,000. A portion of this waste was generated by chemical plants. Considering the greatest number of large chemical plants on the East and Gulf Coasts, a greater quantity of chemical wastes may be discharged to the Atlantic Ocean and the Gulf of Mexico.

Ocean disposal is said to be attractive for those process wastes that are difficult and expensive to treat and discharge without pollution of receiving waters. However, the referenced report failed to find in its survey any comprehensive studies performed to determine potential harmful effects of wastes upon the marine environment and its biota. It is evident from public concern that these studies will be forthcoming with resultant legislation regulating ocean disposal.

Deep Well Disposal. Very little use of deep wells for disposal of solid wastes was reported on the questionnaire. The very nature of most deep wells prohibits disposal of solid materials and even slurries. They are used principally for disposal of liquid wastes, and are therefore a waste water disposal technique.

The deep well disposal technique involves pumping a waste down a well into a porous and permeable subsurface formation. The formation should be porous and permeable over a large area and should possess adequate thickness. Generally, disposal strata consist of sandstone or limestone and, occasionally, fractured shales. The liquid is pumped into the formation, expanding out in all directions. Most installations filter the liquid before injection to remove suspended solids that would plug the formation and render the well useless.

Our survey indicates that unusual conditions exist in certain areas of Michigan. Some companies surveyed there used underground disposal methods for waste liquors containing carbonates, sulfates, silica, and inerts. These compounds are pumped underground with little trouble, although they are present as high concentration slurries.

It must be pointed out, however, that this kind of underground disposal does not fit into the usual category of deep wells. The underground formations in these cases are actually caverns formed by the removal of brines. The salt is in solid form and is dissolved with hot water and pumped to the surface, leaving large cavities.

The number of waste injection wells in use in the United States is not definitely known, but those which are catalogued number slightly over 100. They are scattered over sixteen states with Texas, Louisiana, and Michigan having more than 20 each. A few states have passed laws prohibiting the use of waste injection wells and, of course, such wells are not practical in some areas because of unsuitable geologic formations.

Disposal Agencies

In the management of solid wastes, a plant can elect to buy collection, transportation, and disposal services from either private or municipal sources, rather than handle everything itself. Some plants, mainly small plants, are provided with trash collection and/or disposal by their local municipality, financed through general taxation. Most often, however, the plant must provide transportation of trash to municipal facilities and pay by the ton for disposal.

Some chemical process wastes, including sludges and barreled tars, are disposed of at public facilities. Many chemical plants which dispose of trash at public facilities strive to provide private disposal for their process wastes to avoid problems. Due to growing concern in recent years, regulations on the types of waste that may be deposited at public facilities exclude chemical waste. These regulations have increased the burden on chemical plants to provide their own disposal facilities.

Along with municipal waste services, there are also many private companies which provide either waste hauling, disposal facilities, or both, for process and non-process waste. A plant may elect to have certain of its wastes handled by such a company. Sometimes these private companies are also the main agency for disposal of refuse for the surrounding community.

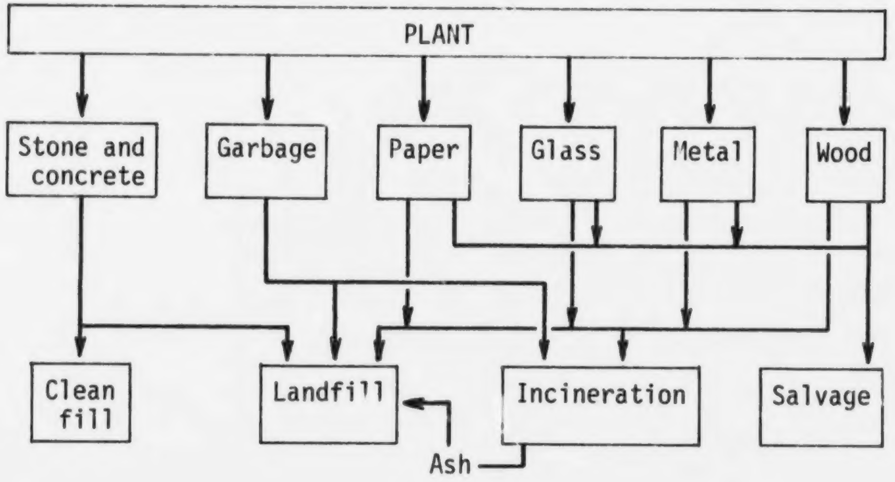
PLANT
Stone and concrete
Garbage
Paper
Glass
Metal
Wood
Clean fill
Landfill
Incineration
Salvage
Ash

Figure 33. Schematic diagram of chemical plant non-process solid waste disposal alternatives.

Development of the Management System

The components of solid waste management systems used by industrial chemical plants have been described in the preceding sections. A chemical plant's selection of which method to use for storage, collection, transportation, and disposal involves many factors. The plant must choose a management system which is economical, efficient, and conforms to health and safety standards.

The type and characteristics of plant solid waste are the most important factors in the development of a management system. Non-process and process wastes exhibit markedly different characteristics and are handled almost entirely by separate systems, although certain operations, such as disposal, may be combined.

Non-Process Waste. Plant non-process waste is generally compatible with municipal refuse, and the decision of whether to use municipal or private facilities or build plant facilities usually is based on local regulations, comparative costs, and the adequacy of municipal or private facilities.

The choice of storage, collection, and transportation systems for non-process waste involves such factors as the length of haul, the number of sources of waste, and the quantity of waste. In addition, choice of equipment depends on comparative costs, flexibility, conformance to health and safety guidelines, ease of maintenance, and compatibility with other plant operations and facilities.

Disposal alternatives are relatively few and are illustrated on Figure 33. Stone and concrete can be used as clean fill or dumped in a landfill. The remaining non-process waste can be disposed by landfill or incineration. If combustible and noncombustible waste is separated prior to disposal, the glass and metal waste can be sent directly to a landfill, while garbage, paper, and wood waste are generally sent to an incinerator. Most chemical plants salvage certain valuable metal wastes for sale. Other wastes such as paper, glass, and

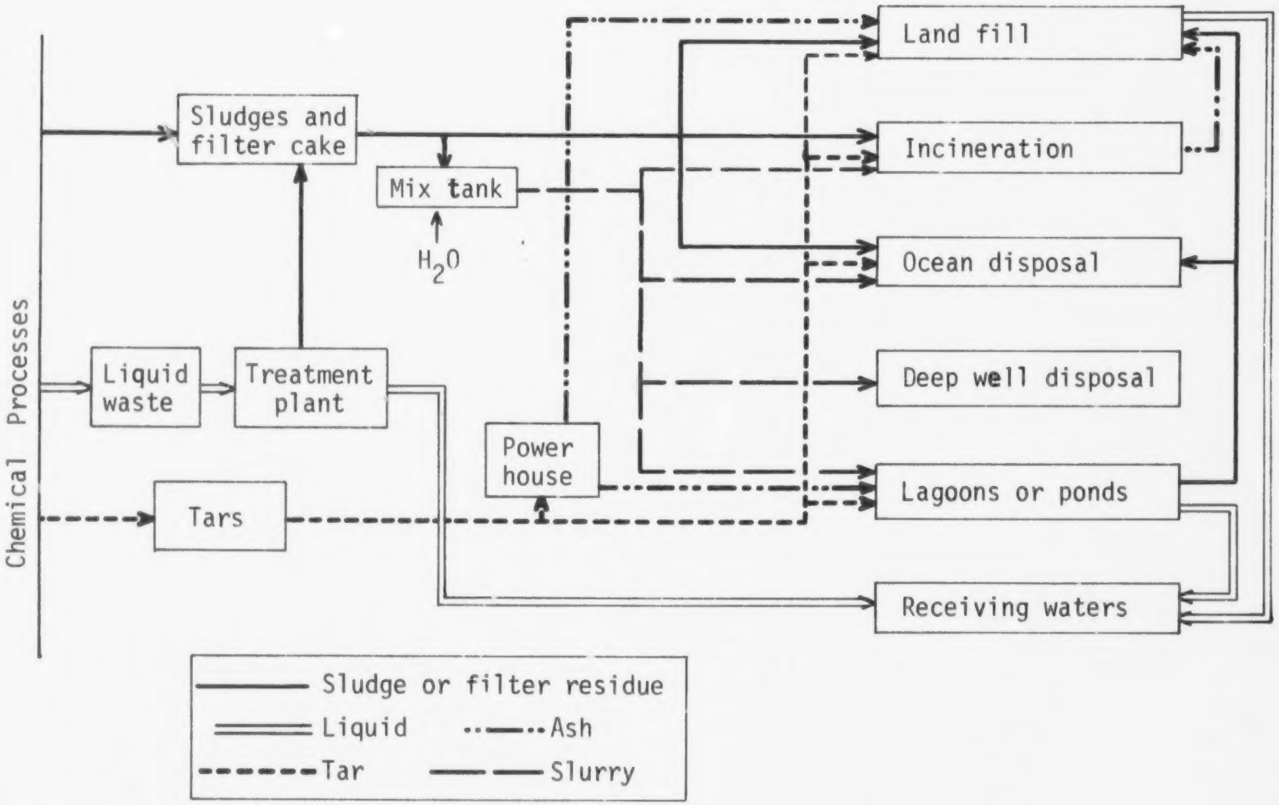
Chemical Processes
Sludges and filter cake
Liquid waste
Treatment plant
Tars
Mix tank
H_2O
Power house
Land fill
Incineration
Ocean disposal
Deep well disposal
Lagoons or ponds
Receiving waters
Sludge or filter residue
Liquid
Ash
Tar
Slurry

Figure 34. Schematic diagram of chemical plant process solid waste disposal alternatives.

wood are capable of salvage but in most cases it is uneconomical and not practiced. The objectives of national solid waste management plans include recycling this material. Salvage operators are available in some areas to take both process and non-process plant wastes for recovery and recyling.

Process Wastes. Solid waste management systems for process wastes require specialized equipment to handle the variety of waste types. Equipment for storage, collection, and transporation of process wastes must be designed for the chemical and physical characteristics of the waste to handle it efficiently. The same factors that influence the choice of non-process waste equipment as listed above influence the choice of process waste equipment. It is of great importance that equipment conform to the intended disposal method. For example, ocean disposal will require barges; ponds used for storage must be lined, and will have to be pumped out into tank trucks or pipelines; and incinerators must be provide/ with storage adequate for the particular wastes to enable proper feeding and mixing.

If the plant elects to use private or municipal disposal facilities, they are freed from the task of developing their own. However, certain process wastes may cause problems with the public or private disposal facility, resulting in adverse public reaction. There are a number of private disposal facilities throughout the country, however, that do employ proper disposal equipment to handle a variety of plant wastes, and where they exist, industries are inclined to use these private facilities rather than build their own.

The disposal methods for process wastes are more varied than those for non-process waste, since they depend on the type and characteristics of the waste to be disposed. Disposal alternatives based on the common waste types are shown in Figure 34. The method used for disposal of sludge or filter cake depends on the consistency of the sludge. If it is a heavy sludge with low water content, three methods are used: (1) It can be landfilled; (2) It can be incinerated either in bulk or in fiber drums; (3) It can be dumped in the ocean either in bulk or in barrels. If the sludge has a high liquid content or is slurried with water to allow pumping, it can be fired through a nozzle and burned in an incinerator, pumped aboard barges and disposed at sea, pumped into lagoons or ponds, or in few cases, pumped into underground wells. Sludges generated by process waste water treatment may be handled in a manner similar to other sludges.

Recycling, Utilization, and Recovery of Process Wastes

The best method of handling solid wastes is to use them to perform a useful function. The industrial chemical industry has a long history of converting wastes into such useful materials, as evidenced by the many commercial products of today which were once considered unwanted chemicals. The large well-staffed research and development departments within many chemical industries are constantly striving to develop useful products from existing or potential waste materials. For example, n-butanol was originally an unwanted byproduct from production of acetone by fermentation. Today it has many uses, such as in glycol ethers, amine resins, solvents, and n-butyl acetate. Demand is predicted to be 580 million pounds by 1971.(46) As a further example, p-toluene sulfonamide was once a residue from production of saccharin. Today it is a useful material in the plastics industry.

The conversion of a waste to a valuable product has been assisted by the stability of chemical markets. Once demand is established for a particular chemical, it generally remains, so when a market is established for a waste, the waste generally becomes a permanent plant product. This may be in part why information was not available from the survey on the numbers and quantities of waste materials converted to useful products. When a waste is converted to a product, it is not viewed by industry as a salvaged material or as a saleable waste, but as a revenue-producing plant byproduct or product.

A benefit is realized from a waste either by recycling, recovery, or utilization of the waste. Recycling of a waste involves returning the waste to the production cycle to be used again. This practice not only reduces or eliminates unnecessary waste, but also is essential to the economic and efficient operation of many processes. Some examples of recycling are described in Section Five. The production of toluene, shown in Figure 7, generates a still bottom from the final refining column. This material is recycled back to the primary column, where it is consumed in the process. In the production of toluene diisocyanate shown in Figure 14, a final fractionating column is added to remove that portion of the residue containing toluene diisocyanate and to recycle it back to the second fractionating column to undergo purification again. In some cases where malfunction in a process results in off-quality product, it is possible to reprocess the material by recycling it back into the process. Waste recovery applies to the reclamation of valuable constituents from waste matter. A prime example is heat recovery from organic waste with usable BTU values, either by firing directly into power plant boilers or from incinerators equipped with waste heat boilers.

Another example is the utilization of lime from acetylene manufacture from calcium carbide. The chemical reaction is as follows:

calcium carbide + water = acetylene + calcium hydroxide

Some of this lime comes from a dry process, but the vast bulk of it is produced as a 10 percent solids slurry. This slurry is almost invariably pumped to diked areas where it eventually concentrates to some extent. In recent years, the number of plants generating acetylene from calcium carbide have decreased, but the ponds remained as eyesores. Now, however, they are gradually disappearing because of the efforts of a New Jersey-based salvage operator who is selling the waste for acid neutralization. The lime can be converted back to quicklime by calcination according to the reaction:

calcium hydroxide + heat = calcium oxide + water

The process has never been widely practiced because it is usually cheaper to buy fresh quicklime than it is to convert the hydroxide.

Recovery of nickel from nickel catalyst used in hydrogenation processes is an example of extraction of a valuable material from a waste. Spent nickel catalyst consists of 10 percent nickel and 40-50 percent clay with the remainder inert. The spent catalyst is sent to Europe where the valuable nickel is recovered.

Other recovery operations consist of reclamation of contaminated chemicals. The reclaiming of solvents is a good example of these operations. In many cases solvents can be reclaimed by simple distillation. Purification or upgrading of off-quality product waste would also be included.

Utilization of a waste is the act of using the waste to obtain a particular benefit. The use of flyash in treatment of polluted water, neutralization of acid mine drainage, and as a binder in soil or roadway conditioning are good examples of waste utilization. Flyash is also used as a constituent in concrete or related products, and in conditioning of wastewater sludge prior to vacuum filtration. However, it has been estimated that only 10 percent of the flyash generated is utilized to any degree.(63)

Other examples of waste utilization include the use of waste tar from synthetic alcohol production in the manufacture of bitumen-type binder. A mixture of bauxite residue and fuel that has been pelletized and sintered, has been used as lightweight aggregate. A relatively unsuccessful utilization of wastes was the use of red mud generated by alumina production to produce iron, which turned out too hard, and in manufacture of bricks, which turned out too soft.

Chemical plant operators are most familiar with the chemical and physical properties of their waste, and are therefore best able to practice recycling, recovery, or utilization of the waste. Benefit derived from recycling a waste into a process must be significant in relation to the total volume of waste recycled. If a large volume of waste must be recycled to obtain a relatively small benefit, the process cannot operate efficiently or economically. Two examples of wastes which would be uneconomical to recycle are wastes from titanium dioxide production and red mud from alumina production, although these waste muds and wash waters do contain substantial percentages of titanium dioxide and aluminum oxide.

Recovery or utilization of wastes by the plant involves possible use in other processes within the plant, sale to companies dealing in waste salvage, or sale directly to consumers. The process of finding a market for a waste is expensive and time-consuming. It is an "extra" task for the marketing staff, who may not have experience in the necessary marketing area, and storage costs for the waste are usually high. In addition, the waste may compete with a customer's product, and too, there is the chance of divulging process secrets by inference.

There are only a few independent chemical waste salvage companies operating in the country, but demand for their services is growing. This type of company may be in the best position to find and develop markets for chemical wastes. Their marketing staff is specifically oriented toward this area, and they are better able to provide consistent and sufficient quantities to their customers.

These firms buy wastes and either process them into saleable materials or sell them directly. The wastes must generally be obtained from a number of plants so that their investment in processing equipment and marketing is not dependent on the operations of one company. Marketing of wastes is hampered by high storage costs and high freight rates for both shipping and receiving which increase the final price of the waste product to the consumer. In addition, some wastes come in quantities that are too small to be attractive, or are cyclic, prohibiting a continuous market, or their chemical content is variable, making it difficult to meet required chemical specifications.

The potential consumers of salvaged waste products are the most important economic factor in development of markets. Their substitution of salvaged wastes for production chemicals is based almost entirely on economics. The waste must be available at an attractive price, meet chemical specifications, contain no deleterious impurities, and be available in significant quantities.

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SECTION SEVEN: SURVEY PROGRAM AND RESULTS

This section discusses the purpose, design, and results of the survey carried out to identify the nature of the solid waste problem in the industrial chemical industry.

Purpose

The purpose of the survey program was to obtain information directly from chemical producers as to solid waste quantities, practices, and future trends, and to relate these, where possible, to basic industry statistics, manufacturing practices, and historical trends. The information was to be analyzed on the basis of various industry classifications, plant size categories, and geographical distributions.

The information was to be obtained by means of a mailed questionnaire and by direct contact interviews. The latter were intended both to provide a more detailed understanding of industry solid waste practices, and to assure that the mail survey was providing representative information.

Secondary objectives of the survey program included the identification of information gaps, and the formulation of recommendations for action leading to their elimination.

Approach and Methodology

Development of Questionnaire Format and Survey Plan. Pilot Program. A pilot program of plant visits was conducted in the early months of the study. This program was primarily intended to solicit industry participation in the structuring of mail and interview questionnaires and formats. The pilot program included contact with the individuals responsible for environmental activities at the corporate level for each plant visited. The Manufacturing Chemists Association provided valuable assistance in making the necessary contacts. Five plants were visited.

The pilot program resulted in many suggestions and comments concerning the content and structure of the questionnaires. Among these were strong warnings against questions relating to plant production and fiscal matters. These, if asked, would not be answered and would very likely prevent any response at all. Other valuable information obtained through the pilot program included suggested process waste categorizations, and the recommendation that the same questionnaire be used for both the mail and plant visit portions of the survey.

After the pilot program was complete and the results reviewed with the Federal program, the questionnaires were finalized for approvals. Samples of both questionnaires are included herein for reference. In addition to the industry questionnaire, a brief questionnaire for mailing to municipal solid waste officials was also prepared. (See Municipal Questionnaire.) The approvals of the questionnaires from the Bureau of the Budget required far more time than was anticipated. The six week delay initially projected stretched to four months.

Survey Mailing. Based on 1967 industry statistics, there were 2,030 establishments engaged in the manufacture of industrial chemicals (SIC 281) in the United States. Project officials intended to mail the industry survey questionnaires to as many of them as possible. The mailing list was developed from the Stanford Research Institute's (SRI's) Directory of Chemical Producers.(20) This directory does not segregate listings according to SIC classifications, so that the products produced by each plant listed had to be checked against those listed for SIC 281. This procedure involved considerable judgment. The address list developed provided over 2100 establishments.

The mailing list for municipal questionnaires was developed on the basis of the geographical distribution of the industry, the distribution of establishments to be sent questionnaires and from readily available listings of municipal officials, such as the Municipal Index, published by the Buttenheim Publishing Corporation.

There were no particular difficulties in preparing the lists or the questionnaires for mailing. Each questionnaire was coded with an identification number to aid in its subsequent classification if it was returned without the plant name and address. No attempt was made to obtain specific names of plant officials. The mailing was addressed to "Plant Manager" in all cases. The identification number indicated the region in which the plant was located to facilitate subsequent data analysis. The regions chosen for this analysis were the Public Health Service Regional Designations of 1969, shown in Figure 35. They were chosen to allow easy comparison of this study data with that developed through other studies conducted by the Public Health Service.

Responses arrived almost immediately, primarily from the small plants. These firms were apparently not constrained by extensive review and approval procedures. In many cases, the company president completed the questionnaires. Many of the larger corporations which replied required several months, and frequently the replies from the various plants arrived in sizable groups, indicating that a general corporate release had been granted. The mail strike, which occurred shortly after the mailing, had little effect.

Table 25 summarizes the distribution of responses before processing. As expected, because of the judgments applied to the SRI Director, many responded negatively in terms of "Not SIC 281". In addition, a surprisingly high number were initially returned because of "insufficient address" or "moved-forwarding address unknown", etc. Even though some attempt was made to correct addresses and remail these, a significant number of the mailings remained in this category.

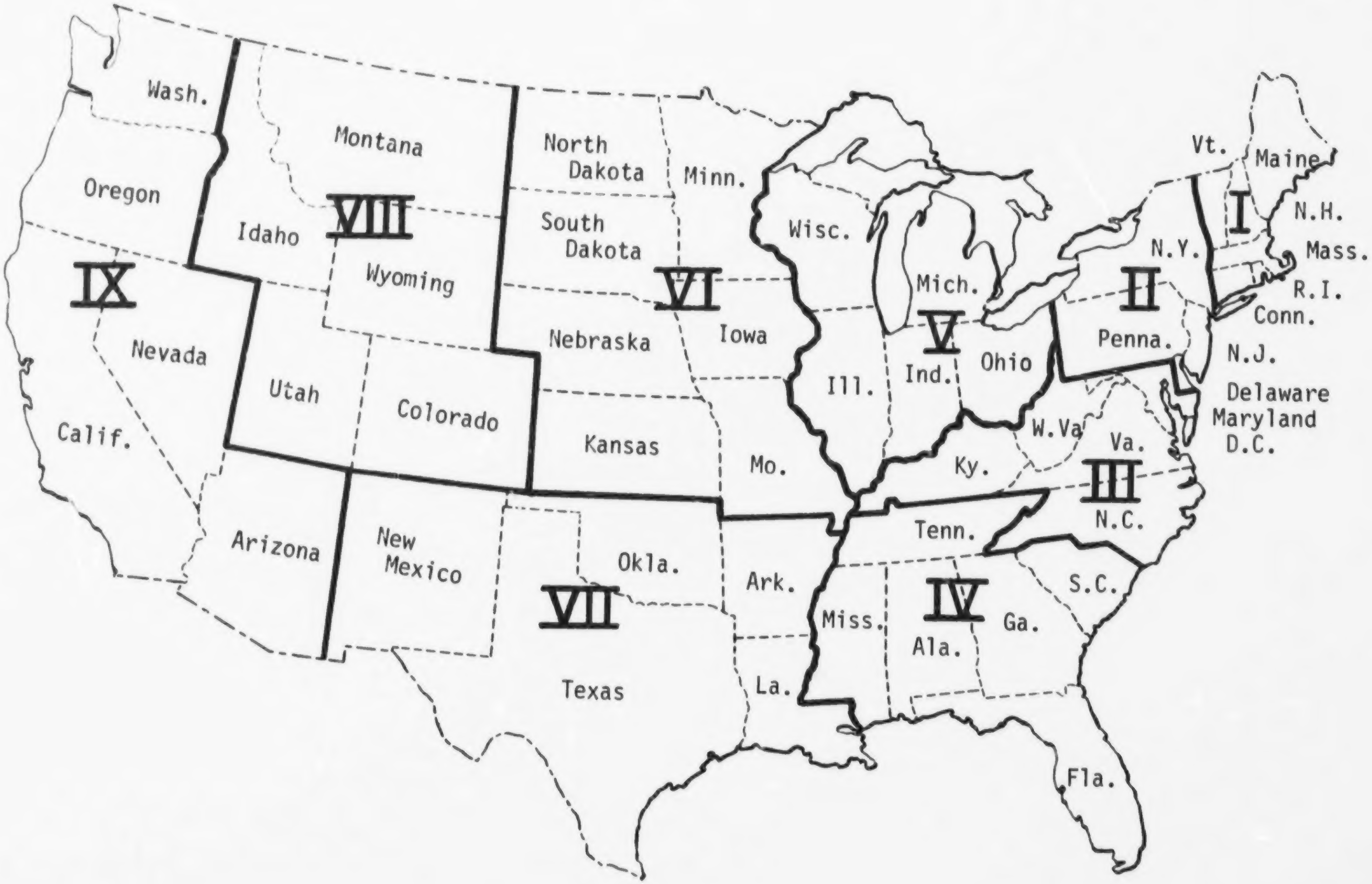
Wash.
Oregon
Calif.
Nevada
IX
Idaho
Montana
VIII
Wyoming
Utah
Colorado
Arizona
New Mexico
North Dakota
South Dakota
Nebraska
Kansas
Minn.
Iowa
Mo.
VI
Okla.
Texas
VII
Ark.
La.
Wisc.
Ill.
Mich.
Ind.
Ohio
V
Ky.
W.Va
Va.
N.C.
III
Tenn.
Miss.
Ala.
Ga.
S.C.
Fla.
IV
N.Y.
Penna.
II
Vt.
Maine
N.H.
Mass.
R.I.
Conn.
I
N.J.
Delaware
Maryland
D.C.

Figure 35. U.S. Public Health Service Regional Designations, 1969.

TABLE 25

SUMMARY OF QUESTIONNAIRE RESPONSE DISTRIBUTION

Region	No. of plants receiving questionnaire	No. of mail questionnaires coded for processing	Plant visits	*Response percentage
I & II	491	64	7	13.0
III & IV	389	48	5	12.3
V & VI	414	44	5	10.6
VII	346	35	6	10.1
VIII & IX	318	34	5	10.7
Totals:	1,958	225	28	11.5

$$\text{*Response percentage} + \frac{\text{No. of mail questionnaires coded for processing}}{\text{No. of plants receiving questionnaire}} \text{ X } 100$$

There were originally over 2100 plants on the mailing list, but approximately forty were held back because these were candidates for plant visits. Table 25 shows that a remarkably consistent response percentage was obtained throughout the country. The overall response rate of about 12 percent was considered satisfactory, although the original goal was 15 percent or better. Some multiplant corporations limited their total number of responses, thereby depriving the survey of responses where they had been expected.

Plant Visit Survey. Since the purpose of the plant-visit portion of the survey program was largely to support and confirm the findings of the mail survey, it was considered vital that the visit ditribution provide a representative cross-section of the industry.

The geographic distribution of the visits was designed to match the questionnaire mailout distribution as closely as possible. Table 25 shows that this end was reasonably achieved. Only regions I, VI, and VIII were not covered by plant visits, as these regions account for only about 12 percent of the total number of questionnaires mailed. The ratio of plant visits in each region to total plant visits when compared to the ratio of questionnaires mailed in each region to total questionnaires mailed, shows agreement.

In selecting the plant-visit distribution, an attempt was also made to account for likely variations due to plant size and area of chemical manufacture. Total plant employment was selected as the size parameter, and four digit SIC classification (SIC 2812, 2813, 2815, 2816, 2818, and 2819) as the area of manufacture category. Four plant size classifications were used: small (less than 100 employees), medium (100 to 500 employees), large (500 to 1,000 employees), and extra large (more than 1,000 employees).

The desired combinations of size, SIC classification, and geographic location were initially developed based on random selection. Then, these were adjusted during conferences with the Federal program, and finally adjusted to reflect the realities of which plants were willing to be visited and when. Originally the candidates for the visits were restricted to regions II, V, and VII, the regions most active in chemical manufacture, and were to be limited to a total of 24, including the pilot program. Economies in travel expenses permitted the expansion of the visits to include California (region IX), and scheduling difficulties led to the visits in regions III and IV.

During the pilot program, a few visits were made to municipal agencies in the areas of the chemical plants visited and these are reported on later in this Section. The information obtained was of limited value; thus these visits were discontinued during the balance of the plant-visit program.

Data Analysis. Data processing was structured for computer techniques. A coding form was developed which transferred the "raw" questionnaire replies into a format amenable to keypunching. The coding of the entire complement of usable replies was accomplished by the same individual, thereby assuring a consistency of interpretation and judgment in those areas where subjective aspects were involved. This same individual was also involved in most of the plant visits.

There were no particular difficulties in coding the replies. The only replies not coded were those from plants not under SIC 281 or those which answered little or none of the questions on the form. In some cases, the numerical replies seemed somewhat inconsistent; e.g., large waste tonnage for small or medium-sized plants. Attempts were made to check the validity of the responses by analyses of the processes involved and other means. It was decided, however, not to make contact with individual plants since if a few plants were called, expecially those generating large waste quantities, this could bias the data. In most cases a reply was accepted at face value, with only occasional responses discarded due to obvious errors.

Since we did not ask each plant to identify its applicable plant SIC number, which would have meant including a detailed list of SIC numbers and the products they included and thereby increasing the complexity of the questionnaire, TRC assigned the appropriate SIC numbers to the questionnaire returns. Assignment of SIC number was based on process wastes reported on the questionnaire and data for the plant found in the SRI directory.

Since only 225 individual questionnaires were coded, it was decided jointly with the Federal solid waste management program not to program for response analysis on the basis of complete combinations of four plant size categories, six SIC classifications, and nine geographic regions. This practice would lead to 216 combinations for each question, with about an equal number of total replies. Most combinations would have registered either zero replies or such a low number as to preclude any conclusions. It was therefore decided to consider the combinations on the basis of three arrangements. Plant size would be considered jointly with SIC classification (24 combinations). The geographical variations were reduced to five by combining regions I and II, III and IV, V and VI, and VIII and IX. These geographical areas were then analyzed with the six SIC classifications (30 combinations) and then with the four size classifications (20 combinations; total of 74).

The 28 plant visits were coded and processed by the computer program in the same manner as the mail responses. This decision was intended to permit comparisons which might point to inconsistencies in the mail survey results. Because of the small universe involved in the plant visits, only gross comparisons were possible. Samples of the computer printout for the mail survey responses are included in the appendix.

Data analysis is discussed in detail later in this Section. In general, many combinations of size, SIC classification, and geographic region resulted in too small a response to permit analysis (i.e., small plants in region V of SIC #2818; large plants in region I of SIC #2815; etc.). In many cases, meaningful comparisons were possible only with the gross results (i.e., all small plants vs. all medium plants; all SIC 2812 plants vs. all 2816 plants; etc.).

There were some comparatively high individual solid waste tonnages reported which greatly influenced the mean calculated for the particular response categories. In most cases, scrutiny of the questionnaire from which the value was derived indicated that the reply was valid as provided by the respondent. In these cases, although the standard deviation and mean calculated for the response showed that the high value was clearly inconsistent with the rest of the individual values, there was no choice but to accept the response. To arbitrarily delete it because "it looked too high" would introduce an unwarranted bias in the results.

Distribution and Industry-Wide Coverage

Distribution. The distribution of responses to the mail questionnaire is summarized in Tables 26 and 27. These tables illustrate the overall "processed" response; that is, 225 responses were processed to the extent that their major areas of activity were assigned (by SIC classification). The distributions shown do not represent responses to all questions on the questionnaire. For example, replies to Question #2 totaled 203 for quantities of combustible waste, 179 for quantities of noncombustible waste, and 144 for quantities of salvageable metal.

As a further example, replies to Question #4 gave 131 responses for quantitites of sludge process waste, 72 for quantitites of filter residue process waste, 37 for quantitites of tar process waste, 19 for quantities of flyash process waste, 24 for quantities of off-quality product process waste, and 30

TABLE 26
DISTRIBUTION OF RESPONSES TO MAIL QUESTIONNAIRE BY PLANT SIZE AND SIC CLASSIFICATION*

Classification	Number of responses	Percentage
Small plants (0-100 emp.)	136	60.4
Medium plants (100-500 emp.)	61	27.0
Large plants (500-1000 emp.)	14	6.3
Extra large plants (more than 1000 emp.)	14	6.3
	225	100.0
SIC 2812	14	6.3
Small plants	8	
Medium plants	6	
SIC 2813	36	16.0
Small plants	34	
Medium plants	2	
SIC 2815	31	13.0
Small plants	13	
Medium plants	8	
Large Plants	7	
Extra large plants	3	
SIC 2816	4	1.7
Small plants	2	
Medium plants	1	
Extra large plants	1	
SIC 2818	49	21.8
Small plants	24	
Medium plants	15	
Large plants	2	
Extra large plants	8	
SIC 2819	91	40.4
Small plants	55	
Medium plants	29	
Large plants	5	
Extra large plants	2	
	225	100.0

*Processed responses only.

TABLE 27

DISTRIBUTION OF RESPONSES TO MAIL QUESTIONNAIRE BY PLANT SIZE AND GEOGRAPHICAL CLASSIFICATIONS*

Classification	Number responses	Percentage
Regions I & II	64	28.4
Small plants	31	
Medium plants	21	
Large plants	5	
Extra large plants	7	
Regions III & IV	48	21.3
Small plants	31	
Medium plants	10	
Large plants	6	
Extra large plants	1	
Regions V & VI	44	19.6
Small plants	27	
Medium plants	13	
Large plants	2	
Extra large plants	2	
Region VII	35	15.6
Small plants	22	
Medium plants	8	
Large plants	1	
Extra large plants	4	
Regions VIII & IX	34	15.1
Small plants	25	
Medium plants	9	
	225	100.0

*Processed responses only.

TABLE 28

MAIL SURVEY COVERAGE OF INDUSTRIAL CHEMICAL PLANTS BY REGION

Region	On basis of plants with 20 or more employees percent	On basis of value added by manufacture percent
Regions I & II	17	11
Regions III & IV	15	19
Regions V & VI	11	10
Regions VII	15	25
Regions VIII & IX	16	9
Overall	14	14

for quantities of other process wastes. Thus a total of 333 responses were received concerning quantities of process wastes.

Further detail is presented later in this Section where the responses to individual survey questions are analyzed.

Industry-Wide Coverage. Comparison of Table 9 with Table 26 gives an indication of the depth of coverage of the survey response. In the medium, large, and extra large categories, the response percentage exceeded the census percentage, while in the small plant category, it fell substantially short. These figures are perhaps indicative of the greater awareness of environmental problems on the part of the larger plants. Thus, while the survey provided a 12 percent overall sample, it gave a 29 percent coverage of the extra large plants, a 24 percent coverage of the large plants, and a 19 percent coverage of the medium plants. The small plants were represented only to the extent of 8.5 percent, however.

In SIC 2812, the response covered 32 percent while in SIC 2813 it covered 7 percent. For SIC 2815, the response provided an 18 percent coverage, while in SIC 2816, only a 4 percent coverage was achieved. In SIC 2818, the coverage was 10 percent, and in SIC 2819, it was 13 percent.

Table 42 of the appendix gives the value added by manufacture in 1967, by geographical region and for plants with 20 or more employees. There is no precise way to determine which of the 136 small plant responses to the survey employ more than 20 persons. However, if there are 1600 total establishments with less than 100 employees, 2030 total establishments and 989 establishments with more than 20 employees, there are 35 percent (100[1 - 2030 - 989/1600] = 35 percent) of the plants in the 0-100 employee category who have more than 20 employees. If it is assumed that 35 percent do indeed have this characteristic, then the survey response on a geographical basis is as shown in Table 28.

In general, therefore, it appears the survey provides an adequate coverage of the industry in terms of the plant size, SIC, and geographical categories selected. Analysis of the data obtained during the 28 plant visits, when compared to those obtained from the mail survey, pointed up no significant deviations or contradictions. Thus the findings of the plant visits are considered to have confirmed the results of the mail survey response. Further details will be provided later in this Section.

Discussion

This Section will provide a question by question analysis of the survey response.

Question 1-General Plant Information.

Total plant employment. The response to this question is summarized in Table 26. While the response came largely from "small" plants (60.4 percent), this figure fell short of the census of small plants (79 percent), while the responses in the other categories exceeded census figures. This matter was discussed in more detail previously in this Section.

Size of Plant Site. The average plant surveyed by mail occupied 199 acres, of which 44 percent was devoted to production facilities. The responses ranged from one acre to 3,917 acres. The average acreage increased significantly with the plant-size category (employment), ranging from 49 acres for small plants to 823 acres for the extra large plants. The extra large plants utilized a higher percentage (52.3 percent) of the plant area for production. SIC 2812 and 2813 plants occupied smaller average plant sites (76 and 69 acres, respectively) than SIC 2815, 2818, and 2819 plants (252, 291, and 205 acres). The SIC 2816 response was too small for meaningful conclusions.

All plant size categories in all SIC's exhibited considerable variability in plant-site size. Even in SIC 2818, for extra large plants, the plant-site size response ranged as low as 20 acres and as high as 3,917.

In all plant sizes, regions I and II and regions VIII and IX have plants whose acreage is less than the average and which have a higher percentage of plant area devoted to production facilities. For example, for medium plants in regions I and II, 19 responses averaged 91 acres, whereas the overall average for 57 medium-sized plants is 266 acres. Overall, regions I and II plants devote 48.5 percent of plant area to production facilities, while in regions VIII and IX, the figure is 57 percent.

In many cases, for subdivision into a specific SIC and plant size or a specific geographic region and plant size, there were insufficient responses to permit analysis.

The plant visit survey plants occupied an average site of 1,041 acres, ranging from 4 to 7,300 acres. A mean of 52.6 percent was devoted to production facilities. The visits surveyed a higher (63 percent) percentage of medium, large and extra large plants, which accounts for the larger value. The tendency for regions I and II and regions VIII and IX plant sizes to be smaller than the mean was supported by the plant visit data.

Nature of Area Surrounding Plant Site. For the mail survey, 41 percent of the responses indicated that the surrounding area was rural, 21 percent said it was residential, 32 percent said it was urban, and 6 percent gave other responses.

For regions I and II the surrounding area was 22 percent rural, 27 percent residential, and 44 percent urban. The higher concentration of plants in urban areas may partially explain why regions I and II exhibit a small average plant site and greater area devoted to production facilities. Many of the plants in this region are located in the highly developed New York-New Jersey metropolitan area. In addition, many of the plants are old and have expanded over considerable portions of their original plant site.

There was no significant deviation from the above mean values in the various size and SIC classifications. The plant visit survey showed fewer plants surrounded by rural (21 percent) and more (36 percent) by residential areas. These figures may be accounted for by the low percentage of small plants visited, although there was no clear indication from the mail survey that small plants were more usually surrounded by rural areas.

Does the Plant Use Public Solid Waste Disposal Sites? Those plants surveyed by mail indicated that 42 percent used public solid waste disposal sites, while 58 percent did not. This response was almost precisely verified by the plant visit survey. The mail survey indicated that small plants (44 percent) and extra large plants (64 percent) used the public waste disposal sites most, while the medium (36 percent) and large (29 percent) used them the least. SIC 2812 plants used them the most (71 percent), and SIC 2813 plants used them the least (31 percent), followed closely by SIC 2819 plants (36 percent). The rest of the SIC classifications were quite close to the overall response.

Plants located in regions I and II and VIII and IX use public sites most (55 percent and 56 percent), while those in regions V and VI, and VII use them the least (33 percent and 23 percent). Plants in regions I and II have indicated a low mean plant site acreage and a high percentage of plant location in urban areas. These figures are consistent with their greater use of public waste disposal sites. Urban areas have fewer land areas suitable for disposal and strict land use regulations which prohibit disposal operations in most areas. In regions VIII and IX, the greater use of public sites is probably due to the highly effective public solid waste disposal systems, although the plants in these regions indicated a much higher degree (46 percent) of rural land surrounding them.

Are There Local, Regional, or State Regulations in Effect That Govern Your Solid Waste Activities? The plants surveyed by mail indicated that 69 percent were governed by solid waste regulations and 31 percent were not. In the plant visit survey, the corresponding figures were 96 percent and 4 percent. Ninety percent of the aggregate of the medium, large, and extra large plants in the mail survey indicated that they were governed by regulations, compared to only 55 percent of the small plants. This seems to imply that regulations do exist in most cases, but that about half of the small plants are not yet aware of them. There were no significant deviations from the overall 69 percent to 31 percent yes-no response in the SIC and geographical classifications.

Question 2-Non-Process Solid Waste Quantities and Activities.

Non-Process Solid Waste Quantities. The respondents were asked for annual quantities of non-process solid waste, either measured or estimated. Ninety-eight percent of them replied that the quantitative information provided was based on estimated rather than measurements. For the plant visit survey, 14 percent indicated that their information was based on measurements.

The results for quantities of non-process solid waste as determined by the mail survey are illustrated by Figures 36, 37, and 38. These figures are bar charts of mean quantities of combustible and noncombustible wastes and salvageable metal, distributed according to plant size, SIC, and geographic classifications. Because of the extremely wide range of the average responses, the charts are constructed on a three-cycle logarithmic scale. While this negates some of the physical "feel" normally associated with bar charts, it was considered necessary to present the information as accurately and concisely as possible.

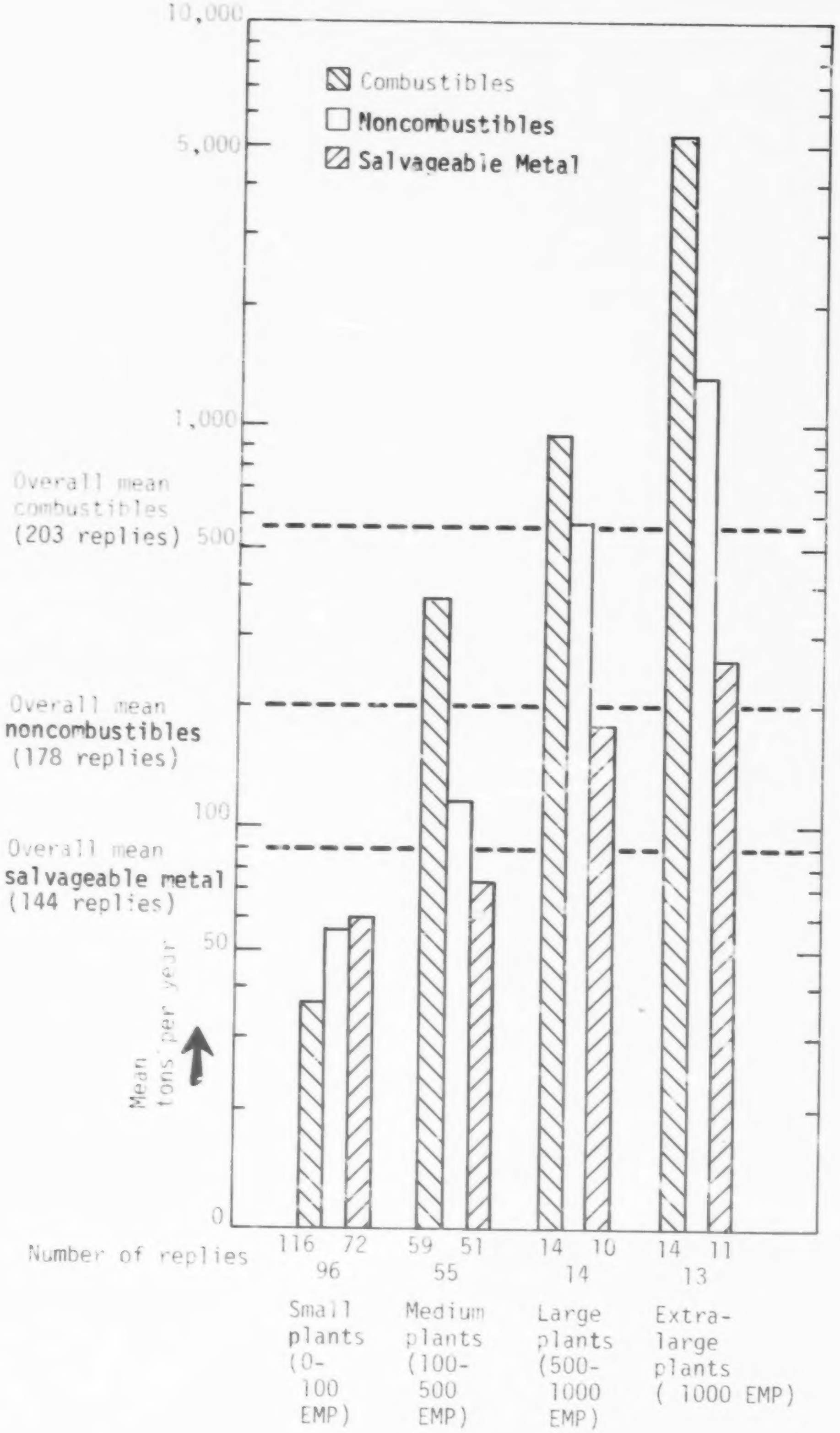

Figure 36. Mail survey results for mean quantities of non-process waste distributed by plant-size classification.

Figure 36 presents the mail response for non-process waste quantities distributed according to plant-size classification. The mean annual tonnage for combustible is seen to range from 37 tons for small plants to 5,340 tons for extra large plants. The overall mean for combustibles is 562 tons per year. The corresponding figures for the plant visit survey were 113, 6,580, and 2,820 tons per year. The higher values for the plant visits are again due to the preponderance of larger plants in the visit program.

For noncombustibles, the overall mean is 207 tons per year, and the relationship of increasing waste quantities with increasing plant size (employment) is evident, ranging from 56 tons for small plants to 1,330 tons per year for the extra large plants. The corresponding figures for the plant visit survey were 95 and 2,180 tons per year, with an overall mean of 1,040 tons per year.

Salvageable metal quantities are generally lower (overall mean of 89 tons per year) with less of a variation due to plant size. The range is from 61 to 264 tons per year for the small to extra large plant-size categories, respectively. One response from a small plant indicated an annual salvageable metal quantity of 3,620 tons. When this figure is deleted, the overall mean drops to 64 tons per year, and for small plants, it is reduced to 10 tons per year. The plant visit survey provided much higher salvageable metal results, ranging from 42 tons for small plants to 3,670 for extra large plants. The overall mean was 1,270 tons per year.

Figures 37 and 38 present the non-process waste quantities distributed according to SIC and geographical classifications. In general, SIC classifications 2812 and 2813 (alkali and chlorine and industrial gases, respectively) exhibit lower non-process waste quantities, due to the preponderance of small and medium plants in the response in these categories. Regions VIII and IX exhibit lower quantities for the same reason, while conversely regions I and II exhibit higher waste quantities because of the large and extra large plants participating in the response.

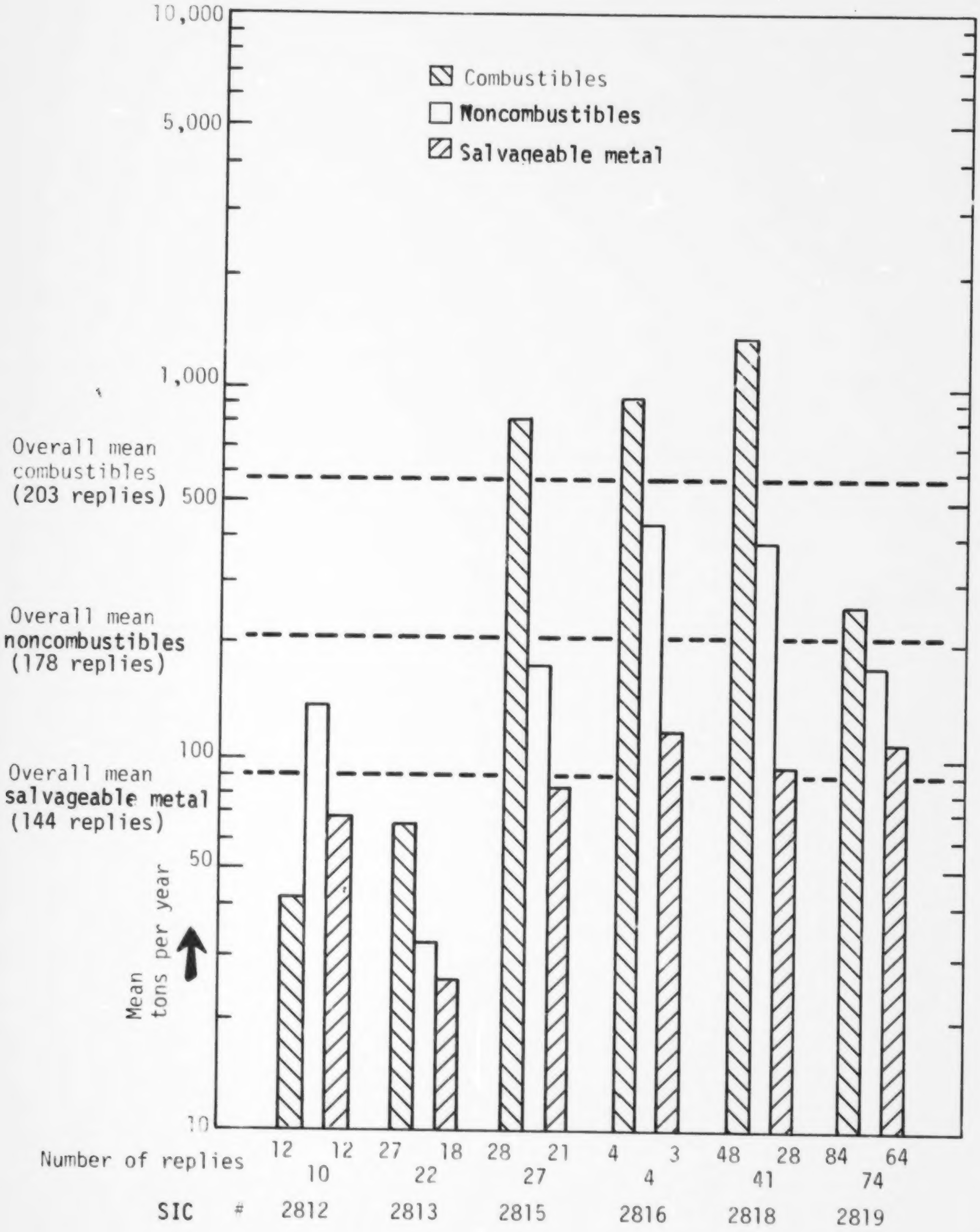

Figure 37. Mail survey results for mean quantities of non-process waste distributed by SIC classification.

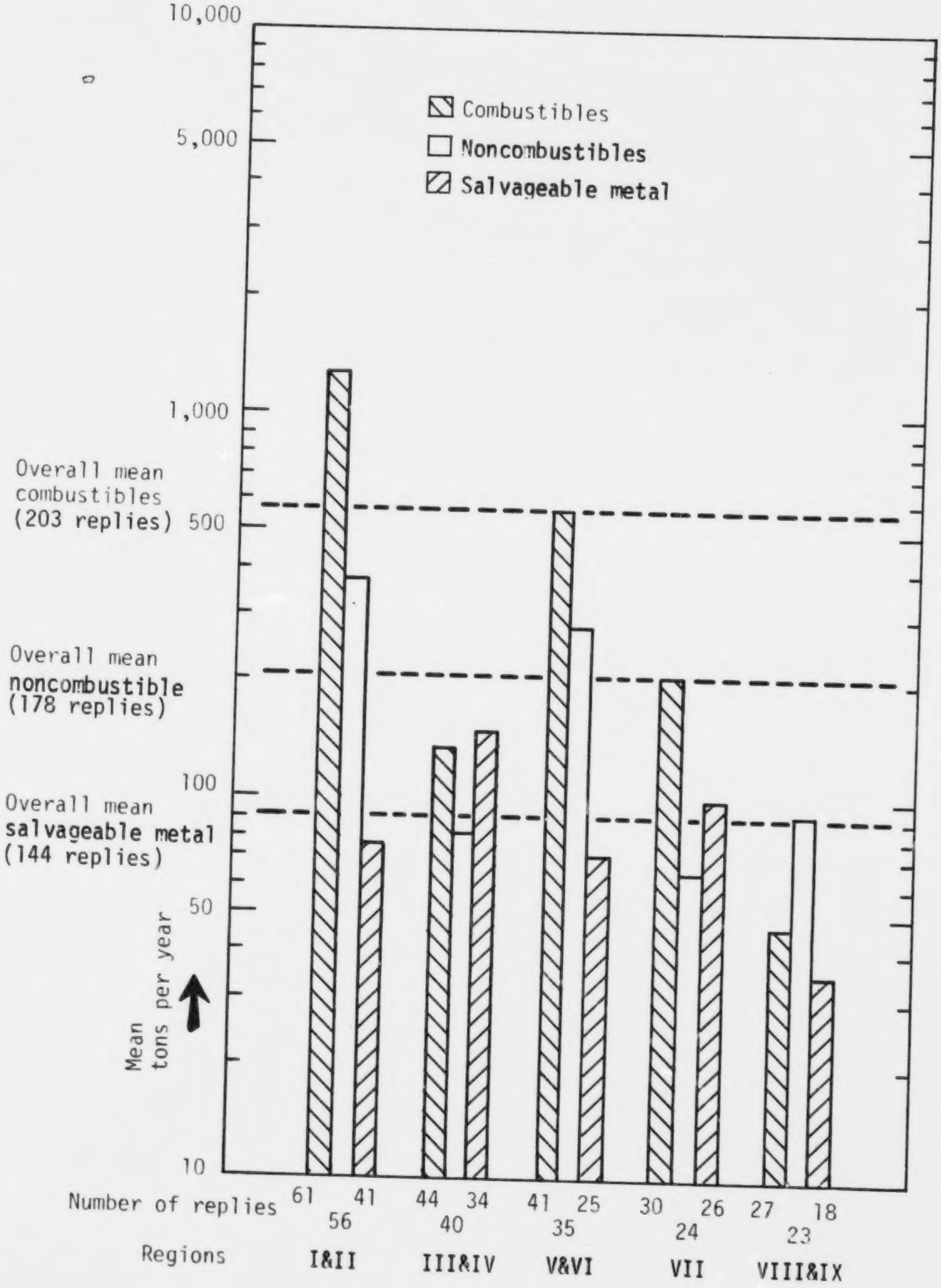

Figure 38. Mail survey results for mean quantities of non-process waste distributed by regional classification.

Analysis of responses to consider detailed combinations of plant-size categories and SIC classifications, or plant-size categories and geographical classifications was not considered plausible because of the small numbers of responses involved.

Non-Process Solid Waste Activities. A number of questions were posed as part of Question 2 relating to waste sources, means and duration of storage, ultimate disposal sites, methods, and costs.

...Waste Sources. On an overall basis, the mail survey respondents indicated that 51 percent of their combustible waste, 42 percent of their noncombustible waste, and 33 percent of their salvageable metal originated in nonproduction areas. Deviations from these mean values for the various plant sizes, SIC, geographical classifications, and combinations thereof were generally not significant. The plant visit survey confirmed the above results with reasonable accuracy (57 percent, 47 percent, and 26 percent respectively).

...Storage Type. Type of storage for combustible non-process waste was reported by the mail survey as 55 percent bulk storage, 4 percent compaction, and 22 percent casual storage. Sixteen percent reported the use of multiples of the above storage methods, while the remaining 3 percent indicated the use of other means. The corresponding values for noncombustible non-process waste were 52 percent, 3 percent, and 27 percent for bulk, compaction, and casual storage; 15 percent for multiple methods; and 7 percent, other means. Thus there was little difference in storage types for non-process waste, whether combustible or noncombustible. For salvageable metals, 35 percent indicated bulk storage and 51 percent casual storage, while 10 percent reported multiple methods and 4 percent other means.

Large and extra large plants showed less combustible non-process waste stored casually and greater use of containerized systems than smaller plants.

Large plants reported 75 percent bulk storage, 17 percent multiple-storage type systems, and only 8 percent casual storage of combustibles. Extra large plants reported only 38 percent bulk storage, but 15 percent compaction and 46 percent multiple-storage systems. No single extra large plant reported all casual storage. Larger plants probably require more efficient storage and collection systems to handle their greater combustible waste quantities and are able to justify purchase of efficient waste storage and collection equipment.

This relationship does not apply to noncombustible non-process waste, and large and extra large plants indicate higher bulk storage of these wastes (83 percent and 69 percent, respectively) than they do for combustibles.

...Storage Period. Overall mean storage period for non-process waste varied from 10 days for combustibles and 22 days for noncombustibles to 119 days (4 months) for salvageable metals. There was little deviation from the above mean values for small and medium plants, but the large and extra large plants had substantially shorter periods. For combustible waste, these storage periods were 3 and 1.5 days, respectively, and for noncombustibles, they were 4 and 2 days. For salvageable metals, the large plant storage period was 78 days, and for the extra large plants, 34 days.

Significant variations with respect to SIC classification, geographical location, and combinations thereof with plant size were few, but included the following:

> SIC 2813: Fourteen small plants reported an average storage period of 50 days for noncombustibles.
>
> SIC 2815: Ten small plants reported an average storage period of 7 days for noncombustibles.
>
> SIC 2813: Eleven small plants reported an average storage period of 260 days for salvageable metal.

The SIC 2813 plants (industrial gases) are generally small, with very low non-process waste quantities. Since quantities are low, longer storage periods are to be expected. There is no apparent reason for the short storage period for the ten SIC 2815 plants. The plant visit survey resulted in longer mean storage periods for combustible and noncombustible wastes (45 and 59 days, respectively) and a shorter period for salvageable metal (89 days).

...Ultimate Disposal Site and Agency. Overall, 35 percent and 33 percent of the mail survey respondents indicated that their combustible and noncombustible wastes are disposed onsite, the balance offsite. The plant visit survey confirmed the overall results for the combustible wastes, but indicated a higher (46 percent) disposal onsite for noncombustibles.

For combustible waste, 52 percent of the offsite disposal takes place at government-operated facilities, 44 percent at private facilities, 2 percent at captive operations, and 2 percent at several of these. For noncombustible wastes, the corresponding results are 47 percent government, 50 percent private, 2 percent captive, and 1 percent multiple. The plant visit survey indicated an even 50-50 split between government and private facilities for both combustible and noncombustible waste.

Except for SIC 2812, there is little deviation from the foregoing mean values when consideration is given to combinations of plant size, SIC classification, and geographic location. In SIC 2812 (alkali and chlorine), six plants replied that 86 percent of their combustible and 71 percent of their noncombustible wastes are disposed at government-operated facilities.

...Ultimate Disposal Method. Overall, according to the mail survey, combustible non-process wastes are disposed of as follows: 43 percent in landfills, 25 percent in incinerators, 13 percent in dumps, 5 percent by open burning, and 14 percent by other methods. Noncombustibles are disposed of 73 percent in landfills, 13 percent in dumps, and 14 percent by other methods.

On the plant visit survey, 75 percent reported the use of landfills for combustibles, 18 percent incinerators, and 7 percent open burning. Landfill was the only method reported for noncombustibles.

The large and extra large plants reported a slightly higher than overall average use of incinerators (36 percent), but there were generally no significant deviations from the overall mean in the various SIC and geographical classifications or in their combinations with plant size. However, regions VIII and IX reported a somewhat higher percentage of use of landfill for both combustible (59 percent) and noncombustible (89 percent) non-process wastes. These figures may be related to the high percentage of plants (45.5 percent) reported in rural areas, and the strict air pollution control regulations in California.

...Cost of Disposal. The mean cost of disposal of combustible non-process waste, according to the mail survey, was $32.80 per ton. This cost includes collection costs and deducts any applicable credits. For noncombustibles, the mean cost was $23.80 per ton, and for salvageable metals there was a $43.80 per ton (approximately $.02 per lb.) credit.

The results for disposal costs and non-process wastes as determined by the mail survey are illustrated by Figures 39,40, and 41.

When the mail response for non-process waste disposal costs was distributed according to plant-size classification, the mean disposal cost for combustibles was seen to range from $38.20 per ton for small plants to $18.60 per ton for large plants (Figures 39 to 41). There is a decreasing per-ton cost with increasing plant size for the small, medium, and large plants, but the trend reverses for extra large plants, indicating possibly a more sophisticated (and more costly) disposal system for these very large plant complexes.

For noncombustibles, the mean disposal cost ranges from $31.60 per ton for extra large plants to $17.80 for large plants. Small plant disposal cost

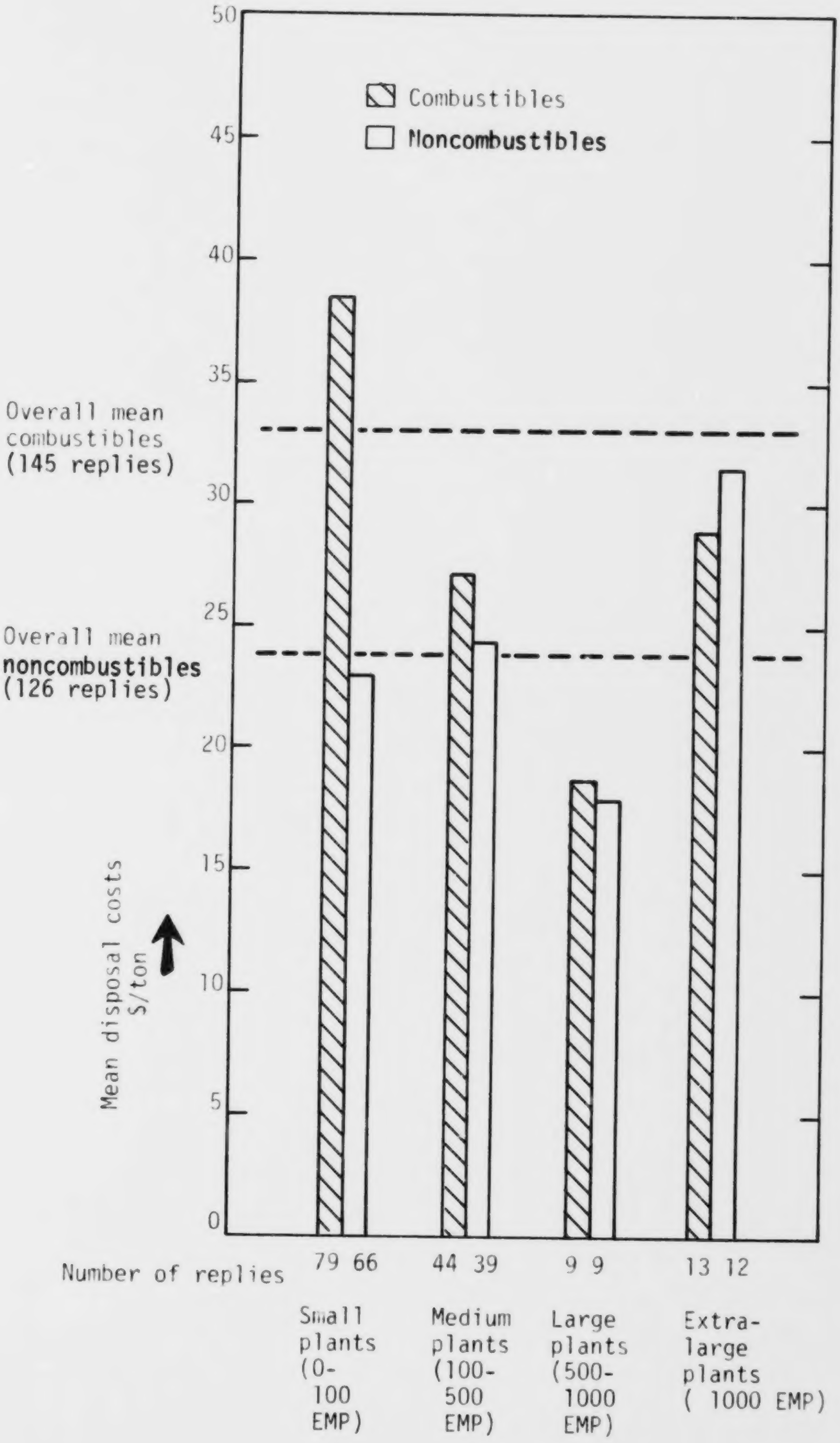

Figure 39. Mail survey results for mean disposal costs of non-process waste distributed by plant-size classifications.

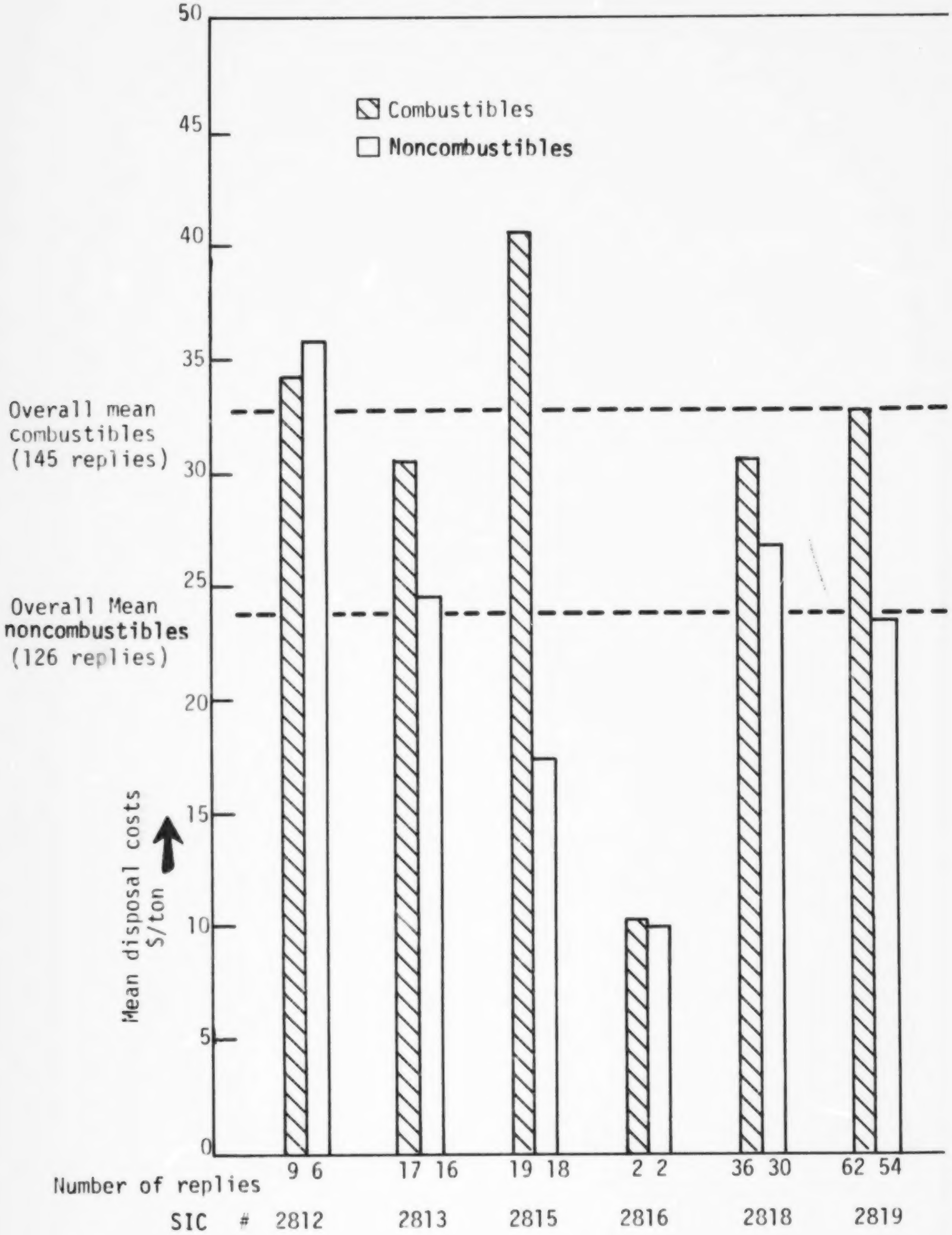

Figure 40. Mail survey results for mean disposal costs of non-process waste distributed by SIC classification.

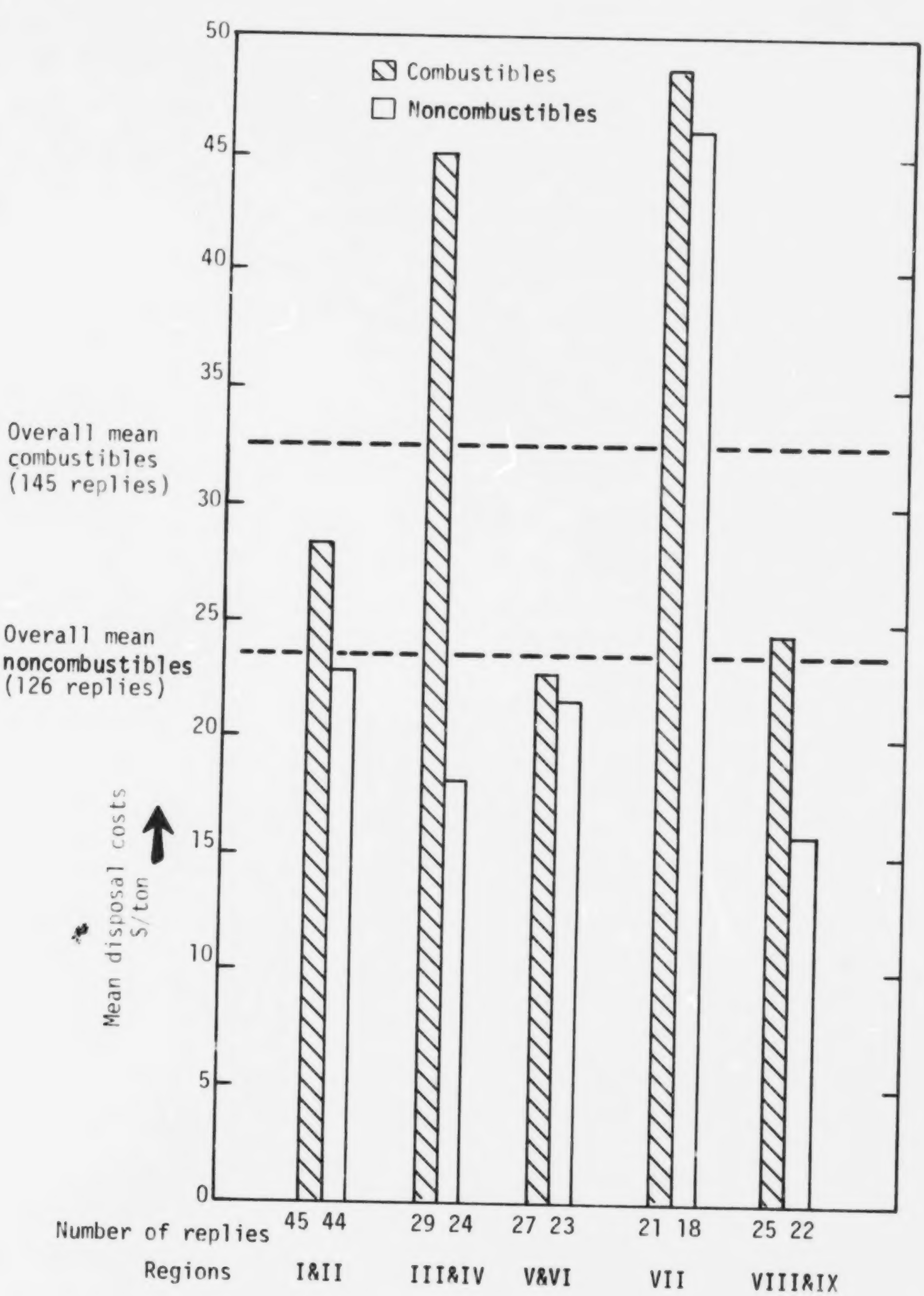

Figure 41. Mail survey results for mean disposal costs of non-process waste distributed by regional classification.

is about the same as that for medium plants. Figure 39 shows that disposal costs for combustible vs. noncombustible non-process waste are essentially the same except for small plants.

Figures 40 and 41 present the non-process waste disposal costs distributed according to SIC and geographical classifications. Except for SIC 2816, where only two responses were obtained, the deviations from the overall mean in the SIC classifications are not significant.

In the regional classifications, the mean combustible disposal cost for regions III and IV was above the overall mean at $45.10 per ton, as was the cost for region VII which was $48.50 per ton. The noncombustible disposal cost for region VII was $46.50 per ton. The balance of the geographical distributions were not significantly different from the overall means. Regions III and IV, and region VII comprise the southern states. Longer hauling costs to off-premise disposal sites could be the predominant factor in these cases, as could difficulties in landfilling due to high water tables and poor soil conditions (e.g., Louisiana and Texas). In most cases, extensive analysis of responses to consider detailed combinations of plant size categories and SIC classifications, or plant size categories and geographical classifications was not considered because of the small numbers of responses involved. There were, however, some exceptions as listed below:

> SIC 2815: Eight small plants reported an average disposal cost of $79.10 per ton for combustibles.
>
> Regions V and VI: Eight medium plants reported an average disposal cost of $11.60 per ton for combustibles. Six medium plants reported an average disposal cost of $7.30 per ton for noncombustibles.

Regions I and II: Eight SIC 2815 plants reported an average disposal cost of $14.60 per ton for combustibles, and $11.60 for noncombustibles. Eight SIC 2818 plants reported an average of $9.20 per ton for combustibles and $9.70 per ton for noncombustibles.

Region VII: Eleven SIC 2818 plants reported an average of $57.60 per ton for combustibles.

The reasons for the above variations from mean values are difficult to pinpoint. Earlier in this Section, a short, seven-day average storage period for ten small plants in SIC 2815 was indicated. This figure would account in part for the high disposal cost indicated above for SIC 2815, since more frequent pickups mean greater costs. The regional variations seem to point to hauling costs as the reason for large differences. Hauling distances are likely to be higher in regions III and IV, and in region VII, and smaller in regions I and II.

For the plant visit survey program, the mean disposal costs for combustible and noncombustible non-process waste were $41.20 and $18.50, respectively, which compare reasonably well with overall means obtained in the mail survey. However, the seven extra large plants surveyed indicated a mean disposal cost of $19.20 for combustibles, which is substancially below the mean and contradicts the mail survey results which showed the extra large plants at approximately the mean value. However, six of the seven plants visited were in regions I and II and in regions V and VI, which in the mail survey exhibited the lowest mean disposal costs for extra large plants.

With respect to salvageable metals, only 18 plants replied to this portion of the mail survey, most of them in SIC 2819. With this size of overall response, it is not possible to analyze beyond the mean value of $43.80 per ton credit reported. In the plant visit survey, only two replies were obtained, averaging $54.50 per ton credit.

Question 3-Identification of Process Wastes. The respondents were asked to identify the number of different process solid wastes which are handled at their plants. They were asked to select from the categories: sludges, filter residues, tars, flyash, off-quality product, and other. For the 213 responses obtained, the average plant generated 1.5 different types of process waste. The small plants averaged 0.9; the medium plants, 2.3; the large plants, 3.2; and the extra large averaged 2.5 different process wastes. Regional and SIC classifications and combinations did not exhibit appreciable variations.

Question 4-Quantities and Sources of Process Wastes.

Sludges. Table 29 summarizes the 131 mail survey responses which indicated quantities of sludge process wastes. The responses ranged from 1 ton per year to a high of 1.67 million tons per year. (This latter response was checked and found to be valid.) The overall mean, and the means for medium plants, for region VII, and for SIC 2819 are all significantly influenced by this value. If it were discounted, the results would be as listed in parentheses on Table 29. The medium plant, region VII, and SIC 2819 values would still be substantially above the mean indicating other high response values in these categories. There were 21 medium plant responses in SIC 2819 which averaged 138,000 (61,000) tons per year, and six SIC 2819 responses in region VII which averaged 448,000 (204,000) tons per year. Thus it appears that sludge waste quantities are significantly larger in the responses from medium plants, from SIC 2819, and from region VII, than they were in other categories. On an individual response basis, there are several plants in this region which manufacture chemicals through processing of ores which leads to extremely large waste quantities.

TABLE 29

SUMMARY OF QUANTITIES OF SLUDGE PROCESS WASTES (TONS PER YEAR)

Plant size classification	SIC classification	Geographical classification	No. of replies	Mean responses
All	All	All	131	*25,400 (12,700)
Small	All	All	52	2,000
Medium	All	All	42	*69,400 (30,400)
Large	All	All	23	11,700
X-Large	All	All	14	2,570
All	All	Reg. I & II	41	3,470
All	All	Reg. III & IV	23	7,450
All	All	Reg. V & VI	26	6,870
All	All	Reg. VII	16	*169,000 (69,400)
All	All	Reg. VIII & IX	25	4,760
All	2812	All	16	1,740
All	2813	All	11	1,180
All	2815	All	18	1,090
All	2816	All	5	2,890
All	2818	All	25	919
All	2819	All	56	*57,600 (28,300)

*These include the single high responses of 1.67 x 10(6) tons per year. The value in parentheses deletes this high response.

Filter Residues. Table 30 summarizes the 72 mail survey responses which indicated quantities of filter residue process wastes. The responses ranged from one ton per year to a high of 3.0 million tons per year. The overall mean, and the means for medium plants, for region VII, and for SIC 2819 are all significantly influenced by this high value. If it were discounted, the results would be as listed in parentheses on Table 30. In this case, the consistency obtained by deleting the 3.0 million value indicates that it was the only response of this order of magnitude. In checking the individual questionnaire which gave this response, it was found that the waste was solids (gypsum from the filtration of phosphoric acid). Thus in spite of its drastic bias of the results for filter residue wastes, it appears to be a valid response. If it is discounted, then the filter residue waste quantities predominate in the responses from SIC 2819 and from small and medium plants and regions VIII and IX where again several high responses for plants processing ores influenced the mean results.

Tars. Table 31 summarizes the 37 mail survey responses which indicated quantities of tar process wastes. With this number of overall responses, it is apparent that even at the level of subdivision of Table 31, analysis of some combinations is not possible. The mean responses for tar waste quantities are seen to be quite consistent, with no significant deviations from the overall mean value. As expected, the tar wastes are generated almost entirely from SIC's 2815 and 2818 (organic chemicals), and largely in region VII which predominates in organic chemical production as shown in Figure 4.

Flyash. Only 19 of the 313 process wastes accounted for by the mail survey response indicated quantities of flyash. These responses averaged 21,830 tons per year per reply, and ranged from 150 to 160,000 tons per year of flyash. The small size of the responses precludes any discussion regarding distribution among plant size, SIC, and geographical classifications.

TABLE 30

SUMMARY OF QUANTITIES OF FILTER RESIDUE PROCESS WASTES (TONS PER YEAR)

Plant size classification	SIC classification	Geographical classification	No. of replies	Mean Responses
All	All	All	72	*42,900 (1,206)
Small	All	All	29	1,040
Medium	All	All	34	*89,700 (1,544)
Large	All	All	6	576
X-Large	All	All	3	370
All	All	Reg. I & II	33	1,200
All	All	Reg. III & IV	15	198
All	All	Reg. V & VI	10	287
All	All	Reg. VII	4	*750,000 (184)
All	All	Reg. VIII & IX	10	3,920
All	2812	All	4	49
All	2813	All	1	6
All	2815	All	7	447
All	2816	All	0	0
All	2818	All	25	193
All	2819	All	35	*87,900 (2,280)

*These include the single high response of 3.0 x 10(6) tons per year. The value in parentheses deletes this high response.

TABLE 31

SUMMARY OF QUANTITIES OF TAR PROCESS WASTES (TONS PER YEAR)

Plant size classification	SIC classification	Geographical classification	No. of replies	Mean responses
All	All	All	37	596
Small	All	All	12	668
Medium	All	All	16	588
Large	All	All	3	692
X-Large	All	All	6	426
All	All	Reg. I & II	9	487
All	All	Reg. III & IV	12	384
All	All	Reg. V & VI	7	846
All	All	Reg. VII	4	1,540
All	All	Reg. VIII & IX	5	196
All	2812	All	2	4
All	2813	All	0	0
All	2815	All	16	885
All	2816	All	0	0
All	2818	All	14	545
All	2819	All	5	53

Off-Quality Product. Twenty-four responses concerning quantities of off-quality product process waste were received. These responses averaged 962 tons per year, and ranged from one ton per year to 9,060 tons per year. There was an orderly progression of quantity with plant size: 25 tons per year for small plants, 907 for medium plants, 1,410 for large plants, and 2,150 tons per year for extra large plants. This relationship may be expected, since off-quality product quantities are directly related to production quantities. Eighteen of the 24 responses were in SIC's 2818 and 2819, and they averaged 970 tons per year. Eight of the responses came from regions I and II, averaging 1,460 tons per year, while thirteen came from regions III and IV and regions V and VI, averaging 169 tons per year.

Other Process Wastes. Thirty responses were received as to quantities of "other" process wastes. These responses averaged 988 tons per year, and ranged from 1 to 15,000 tons per year. Because of the many different types of waste which could be lumped under this category, the responses in the various plant size, SIC, and geographical classifications were quite varied and therefore not amenable to analysis or discussion.

Plant Visits. Table 32 presents a comparison of process waste quantities determined by the mail survey and the plant visit survey. The table shows excellent agreement in some cases and wide variation in others. In the case of the plant visits, questioning of the validity of numerical response is ruled out because of the opportunity to check the values "on the spot" with the respondent. Thus the wide difference in the filter residue response is considered to be real. All other mail responses are considered to be reasonably well supported by the plant visit results. The off-quality product difference is readily accounted for by the greater percentage (83 percent) of medium, large, and extra large plants surveyed in the plant visits.

TABLE 32

COMPARISON OF PROCESS WASTE QUANTITIES AS DETERMINED BY THE MAIL AND PLANT VISIT SURVEYS

Process waste	Mail survey		Plant visit survey	
	No. of replies	Mean waste quantity (TPY/reply)	No. of replies	Mean waste quantity (TPY/reply)
Sludge	131	25,000	27	34,000
		(13,000)*		
Filter residues	72	43,000	8	149,000
		(1,200)*		
Tar	37	600	15	1,750
Flyash	19	22,000	4	20,000
Off-quality product	24	960	7	3,300
Other process waste	30	990	2	600
Overall mean per process waste type	313	22,000	63	36,000
Mean process waste generation per plant	213**	33,000***	26**	86,000***

*The quantities given in parentheses are the mean values obtained when the highest single response was deleted.

**Number of plants reporting process waste.

***Tons per year per plant.

Question 5(a)-Storage and Disposal of Process Wastes. A number of questions were posed relating to waste storage methods and duration, transportation methods, disposal sites, and disposal methods for process wastes. These responses will be summarized by a series of tables giving the overall results. Significant departures from the overall means will be pointed out.

Waste Storage. Table 33 summarizes the overall process waste response regarding waste storage.

The storage period for sludge wastes varied from 211 days for small plants to 32 days for extra large plants. SIC 2813 and 2819 plants had the longest storage periods for sludge waste, 319 and 170 days, respectively. Storage periods for sludge were shorter for regions I and II and regions V and VI (100 and 52 days, respectively).

For filter residue process waste, the storage period varied from 93 days for small plants to one day for the four large plants responding. In SIC 2818, 21 plants averaged 8.5 days, while in SIC 2819, 27 plants averaged 125 days. In regions VIII and IX, seven plants averaged 151 days, but in the rest of the geographical classifications, the storage periods were reasonably close to the mean value of 68 days.

The storage period for tar wastes varied from 52 days for medium plants to four days for the two large plants responding. In regions I and II, seven plants averaged 14 days, while in regions V and VI, six plants averaged 8 days. Twenty-eight of the 32 responses were in SIC's 2815 and 2818, and these were quite close to the mean storage period of 38 days.

For flyash wastes, eight large and extra large plants averaged six days for storage, while four medium plants averaged 106 days.

Off-quality product waste storage periods varied from 51 days for small plants to 5 days for the three large plants reporting. For responses of any

TABLE 33

SUMMARY OF MAIL SURVEY RESPONSES REGARDING PROCESS WASTE STORAGE

Process waste	Mean storage period (days)	Storage method*				
		Container	Casual	Ponds	No storage	Other
Sludge	115 days (83 responses)	45% (56)	9% (11)	23% (28)	22% (27)	1% (1)
Filter residue	68 days (52)	62% (40)	15% (10)	8% (5)	15% (10)	0 (0)
Tar	38 days (33)	85% (28)	12% (4)	0 (0)	3% (1)	0 (0)
Flyash	39 days (12)	43% (6)	15% (2)	21% (3)	21% (3)	0 (0)
Off-quality product	32 days (22)	88% (22)	8% (2)	4% (1)	0 0	0 (0)
Other process waste	13 days (15)	70% (14)	10% (2)	5% (1)	15% (3)	0 (0)
All process wastes	73 days (217)	59% (166)	11% (31)	14% (38)	16% (44)	0 (1)

*Percentages shown relate to the proportion of those plants responding who utilize the indicated storage method for the various process waste.

TABLE 34

SUMMARY OF MAIL SURVEY RESPONSES REGARDING PROCESS WASTE TRANSPORT

	Transport method*				Transport agency*		
Process waste	Truck	Pipeline	Barge	Rail	Captive	Private contract	Government
Sludge	61% (77 replies)	35% (44)	3% (4)	1% (2)	80% (66 replies)	18% (15)	2% (2)
Filter residue	78% (55)	22% (16)	0 (0)	0 (0)	65% (24)	32% (12)	3% (1)
Tar	97% (38)	3% (1)	0 (0)	0 (0)	70% (14)	30% (6)	0 (0)
Flyash	65% (11)	29% (5)	0 (0)	6% (1)	82% (9)	18% (2)	0 (0)
Off-quality product	96% (24)	4% (1)	0 (0)	0 (0)	82% (9)	18% (2)	0 (0)
Other process waste	97% (28)	3% (1)	0 (0)	0 (0)	94% (15)	6% (1)	0 (0)
All process waste	76% (233)	22% (68)	1% (4)	1% (3)	77% (137)	21% (38)	2% (3)

*Percentages shown relate to the proportion of those plants responding who utilize the indicated transport method or agency for the various process waste types (components).

significant numbers, SIC and geographical classifications did not exhibit marked deviation from the means.

For "Other" process wastes, five small and five medium plants reported average storage periods of 31 and 5 days, respectively. Fourteen of the fifteen responses were in SIC 2818 and 2819.

Storage methods did not deviate more than 10 percent from the mean percentages given on Table 33 except for a few instances, when plant size, SIC and geographic classifications, or combinations thereof, were considered. In many of these cases, the number of responses comprising the mean value was quite small and not amenable to analysis or discussion. A few examples include:

> Filter residue waste: SIC 2819: Nineteen plants (83 percent) indicated container storage, compared to an overall mean of 62 percent. Eleven plants (85 percent) in regions III and IV indicated container storage compared to the overall mean of 62 percent.
>
> Tar Waste: SIC 2815: Fourteen responding plants (100 percent) indicated container storage, as did ten in regions I and II (100 percent), compared to an overall average of 85 percent.

Waste Transport. Table 34 summarizes the overall response regarding process waste transport. Seventy-seven percent of the plants reporting process waste employed captive transport facilities with very few reporting government transport. The following are significant deviations from the overall means for the various transport methods.

Eleven extra large plants reported transport of sludge to a greater degree by truck than the overall mean response (79 percent vs. 61 percent), and less by pipeline (21 percent vs. 35 percent). Only two large plants and

TABLE 35

SUMMARY OF MAIL SURVEY RESPONSES REGARDING PROCESS WASTE DISPOSAL*

		Process Waste						
		Sludge	Filter residue	Tar	Flyash	Off-quality product	Other process wastes	All process wastes
Site	Onsite	46% (63 replies)	36% (26)	49% (19)	50% (8)	44% (11)	45% (14)	44% (141)
	Offsite	54% (73)	63% (45)	51% (20)	50% (8)	56% (14)	55% (17)	56% (177)
Nature of offsite disposal	Captive	15% (11)	11% (5)	10% (2)	11% (1)	14% (2)	40% (6)	15% (27)
	Private contract	58% (41)	52% (24)	58% (11)	78% (7)	57% (8)	20% (3)	54% (96)
	Government	27% (19)	37% (17)	32% (6)	11% (1)	29% (4)	40% (6)	30% (53)
Disposal method	Land disposal	68% (91)	76% (51)	71% (27)	59% (10)	83% (20)	80% (24)	72% (223)
	Incineration	4% (5)	10% (7)	24% (9)	0 (0)	4% (1)	7% (2)	8% (24)
	Lagoons	15% (20)	8% (5)	0 (0)	23% (4)	0 (0)	3% (1)	10% (30)
	Ocean disposal	1% (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)
	Other	12% (17)	6% (4)	5% (2)	18% (3)	13% (3)	10% (3)	10% (32)

*percentages shown relate to the proportion of those plants responding who utilize the indicated disposal technique for the various process waste types (components).

two medium plants indicated barge transport of sludges. Truck transport of sludges predominated in regions I and II and in regions V and VI (77%, 31 responses and 77%, 17 responses, respectively), and was least in region VII (35%, 7 responses). Pipeline transport predominated (60 percent, 12 responses) in region VII. All sludge wastes reported in SIC 2815 (16 responses) were transported by truck.

All sludge transport in extra large plants is accomplished by captive facilities (nine responses). The same is true for the extra large plants in SIC 2812 and SIC 2813 (13 responses). In SIC 2815, the transport was split evenly between captive and private contract facilities (eight responses). In regions I and II, 59 percent of the transport (13 responses) was captive, while in regions V and VI and in region VII, transport was captive by 93%, 12 responses and 93%, 14 responses, respectively.

Nine large and extra large plants reported all transport of filter residue by truck. Twenty-four SIC 2818 plants reported 96 percent transport of filter residue by truck. Twelve medium plants (52 percent) reported transport by governmental facilities, as did five (83 percent) SIC 2812 plants.

Waste Disposal. Table 35 summarizes the overall response regarding process waste disposal. The following are significant deviations from the overall means.

Incineration of sludge waste is more prevalent in SIC 2818. Eighteen (75 percent) of these plants indicated incineration of sludge wastes. Three (23 percent) extra large plants are included. Most likely, the solids contained in these sludge wastes are primarily organic materials generated from production of miscellaneous organic chemicals, and therefore are amenable to incineration. Nine of the extra large plants (64 percent) indicated onsite sludge disposal, as did 17 of regions III and IV extra large plants (77 percent). In regions I and II, only 12 (29 percent) of the plants indicated onsite disposal.

In regions III and IV, eight plants (40 percent) responded that incineration was their means for filter residue waste disposal. In SIC 2818, seven (30 percent) indicated incineration for filter residue waste disposal, which again reflects the organic nature of solids in filter residues from this industry segment.

In SIC 2815, seven plants (41 percent) indicated incineration for disposal of tar wastes, as did seven plants (58 percent) in regions III and IV.

Question 5(b)-Cost of Disposal of Process Waste. The respondents were asked to indicate the total disposal cost for each process waste generated as well as the components of that cost (i.e. cost for process waste storage, pretreatment or special handling, transportation, the ultimate disposal method, and any credit). In some categories, a very sparse response was obtained. In many cases the respondents did not segregate total cost into the various storage, transport, etc. components, but did provide the total disposal cost. The mean values reported for these costs are summarized in Table 36.

The component costs reported in columns 1 through 5 on Table 36 are independent of the total disposal costs in column 6. Costs in columns 1 through 5 are the mean of the costs for the particular component operations as reported by those replying to the question, and the costs in column 6 are the mean of the total disposal costs reported by those replying. Therefore, the mean values are based on a different quantity and possibly different types of plants and the component costs (columns 1 through 5) do not add up to total disposal costs (column 6) on the table. Total disposal costs (column 6) were found to be less than the sum of the component costs, except for the off-quality product wastes (credit not included). A possible reason for this is that the individual

TABLE 36

SUMMARY OF MAIL SURVEY RESPONSES REGARDING PROCESS WASTE DISPOSAL COSTS*

Process waste	1 Cost of storage	2 Cost of pretreatment**	3 Cost of transport**	4 Cost of disposal**	5 Credit for salvage***	6 Total disposal cost****
Sludge	$4.00 (14 replies)	$14.70 (22)	$31.20 (47)	$13.10 (51)	$379.80 (5)	$33.00 (65)
Filter residue	$18.00 (8)	$6.70 (4)	$22.40 (21)	$118.50 (22)	$420.00 (2)	$93.80 (46)
Tar	$50.60 (3)	$34.20 (4)	$16.30 (16)	$20.10 (17)	---	$41.70 (26)
Flyash	---	---	$1.00 (6)	$2.00 (5)	$.40 (1)	$2.10 (9)
Off-quality product	$2.00 (4)	$1.00 (2)	%5.90 (11)	$7.60 (10)	$50.00 (1)	$25.70 (13)
Other process waste	$1.70 (3)	$6.00 (3)	$7.30 (21)	$6.50 (13)	$50.00 (1)	$14.00 (20)
All process waste	$11.40 (32)	$14.48 (35)	$19.84 (122)	$32.09 (118)	$283.94 (10)	$44.67 (179)

*All costs shown are mean values and are in $/ton.

**Columns 1 through 5 report the mean of the reported cost for the particular component operations for those replying to the question.

***Much fewer tons are salvaged than are stored, pretreated, transported and disposed of.

****Column 6 reports the mean of the reported total disposal cost for those replying to this equestion and was not derived from the reported component costs.

questionnaire replies of total disposal cost were probably obtained from readily available cost information, such as private contractor invoices, and did not include costs for storage, pretreatment, and onsite transport. These costs are more difficult to obtain, and are not readily available in many plant records.

Study of Tables 32, 33, 34, and 35 in comparison to Table 36 provided only limited insight as to relationships between cost differences and differences in waste quantities, storage, transport, and disposal practices.

Filter residue process waste indicated the highest disposal cost (Table 36). Table 35 shows that 32 percent of this waste is transported by private contract, and Table 34 indicates that 63 percent is disposed offsite, of which 52 percent is handled by private contract. These facts could account for the high disposal cost.

The relatively low cost for storage of sludge wastes may be explained by the fact that only 45 percent of the replies for sludge waste indicated container storage whereas 62 percent and 85 percent of the replies indicated container storage for filter residues and tars respectively.

Off-quality product and other process wastes exhibited lower transport and disposal costs than did sludges, tars, and filter residues. These wastes, largely stored in containers, and almost entirely transported by truck, are probably capable of being packaged more efficiently with resulting economies.

Although the process waste cost distributions differed somewhat in the various SIC and regional classifications, it is not considered worthwhile to report these in any detail. In many cases, the storing, handling, or disposal of a particular type of waste can be unusual enough to result in a high cost response. This occurrence is felt to unduly bias the mean value in a particular SIC, plant size, or geographical combination where only a small overall response was obtained. Therefore, deviations from the overall means do not have sufficient significance to warrant detailed review.

Question 6-Physical and Chemical Characteristics of Process Wastes. The questionnaire asked for chemical and physical characteristics pertinent to solid waste disposal activities. This question received rather sparse response, and was analyzed only to the extent that a process waste was classified as toxic or inert. Table 37 summarizes the results. In general, of the 44 total responses obtained, less than half (40 percent) of the process wastes were considered toxic by the respondents.

Question 7-Waste Generation Parameters. The questionnaire asked for the plant operating parameter which most directly influences waste generation. Table 38 summarizes the results of the response to this question. The response was surprisingly good to the extent that various influencing parameters were identified; however, virtually no quantitative relationships were supplied.

Question 8-Five Year Projection as to Waste Quantities, Disposal Practices and Costs. Significant responses were received only about projected waste quantites. These were expressed in a number of ways, including annual percentage increases, overall (five year) percentage increases, and actual projected tonnages for 1975. All replies were converted for expression in the latter form. They are summarized on Table 39, and when compared with 1970 quantities, it is apparent that substantial increases in most waste categories are anticipated, particularly in the already large quantity areas. In the comparisons of Table 39, no attempt was made to delete the very high responses.

Detailed comparisons between 1970 and 1975 values for the plant size, SIC, and geographical classifications were not considered since it was felt that meaningful relationships could not be established from the limited data.

Plant Visits. The results obtained from the plant visits bear out those

TABLE 37

SUMMARY OF MAIL SURVEY RESPONSES REGARDING PROCESS WASTE CHARACTERISTICS*

Process waste	Toxic	Inert
Sludge	35% (6 replies)	65% (11)
Filter residue	20% (2)	80% (8)
Tar	90% (9)	10% (1)
Flyash	0 (0)	100% (4)
Off-quality product	--	--
Other process wastes	33% (1)	67% (2)
All process wastes	40% (18)	60$ (26)

*Percentages shown relate to the proportion of those plants responding who indicated toxic or inert process waste characteristics.

TABLE 38

SUMMARY OF MAIL SURVEY RESPONSES REGARDING PROCESS WASTE GENERATION PARAMETERS*

	Waste Generation Parameter				
Process waste	Purity of raw material	Degree of reaction	Amount of production	General maintenance	Other
Sludge	48% (43 replies)	11% (10)	17% (15)	6% (5)	18% (16)
Filter residue	41% (19)	11% (5)	20% (9)	2% (1)	26% (12)
Tar	12% (3)	44% (11)	4% (1)	4% (1)	36% (9)
Flyash	89% (8)	0 (0)	0 (0)	0 (0)	11% (1)
Off-quality product	13% (2)	13% (2)	0 (0)	27% (4)	47% (7)
Other process wastes	8% (2)	8% (2)	38% (10)	19% (5)	27% (7)
All process wastes	37% (77)	14% (30)	17% (35)	8% (16)	24% (52)

(Percentages shown relate to the proportion of those plants responding who indicated waste generation parameters.

TABLE 39

SUMMARY OF MAIL SURVEY RESPONSE REGARDING PROCESS WASTE QUANTITIES IN 1975

Process waste	1970 Quantities (mean value tons per year)	1975 Quantities (mean value tons per year)	Increase or decrease %
Sludge	25,400 (131 replies)	39,600 (92)	55% Increase
Filter residue	42,900 (72)	64,200 (50)	50% Increase
Tar	596 (37)	782 (27)	31% Increase
Flyash	21,800 (19)	19,500 (10)	11% Decrease
Off-quality product	962 (24)	654 (14)	32% Decrease
Other process	988 (30)	1,820 (17)	85% Increase
Overall mean per process waste type	22,000 (313)	33,900 (210)	54% Increase

obtained from the mail survey with remarkable consistency, where the size of response is sufficiently large to permit valid comparisons. The storage periods for the various process wastes, as reported from the plant visits, deviate somewhat in the direction of shorter storage intervals. Since the plant visits were predominantly to the three larger plant size categories, this was expected.

A higher degree of incineration disposal was reported for tar in the plant visits than it was for the mail survey (57 percent, 12 responses vs. 24 percent, 9 responses). Five plant visits also indicated incineration disposal for off-quality product, whereas only one mail survey plant reported this combination. These practices were reflected in greater onsite disposal for both wastes in the plant visit survey.

The disposal costs for the plant visits were quite different from those obtained for the mail survey for most process wastes. In most cases, the costs were significantly lower. For example, the overall transport costs were $5.68 (29 responses) per ton for the plant visits and $19.84 (122 responses) per ton for the mail survey. The same type of relationship existed for disposal costs and total disposal costs. This trend is again thought to be attributable to the greater average size of the plant visited, compared to the mail survey. The larger plants generally handled greater waste quantities and achieve lower per ton costs.

The plant visit survey projected generally lesser increases of process wastes for 1975 than did the mail survey.

Municipal Questionnaire

A special questionnaire was sent to municipal and regional officials in jurisdictions where the manufacture of industrial chemicals was known to be a major industry. This questionnaire was designed to supplement the industry survey by providing insight regarding the view taken by governmental officials of the disposal of solid waste from the chemical industry. A sample copy of the questionnaire appears in the Appendix.

A total of 130 copies of this questionnaire were mailed, and 64 replies were received for a response of 49 percent. The distribution in the geographical regions approximated the distribution of mailings to the chemical plants in those regions.

A question-by-question review of the response to this municipal survey follows.

PART A Municipal Refuse Disposal.

Questions 1 and 2. The municipal officials were asked to identify the disposal facilities in their areas of jurisdiction. Responses indicated that 12 percent operated dumps, 92 percent sanitary landfills, and 22 percent incinerators. As can be seen by these figures more than one type of disposal facility was often reported in a single jurisdiction.

Question 3. This question was inadvertently misstated, so that any response received was invalid.

Question 4. The respondents were asked if chemical industries used the reported facilities to dispose of solid wastes. The affirmative responses totaled 66 percent, while 30 percent replied negatively. Of those replying yes, 19 percent disposed of these wastes in dumps, 83 percent in landfills, and 2 percent in incinerators. (Here too there were some multiple replies.)

Question 5. The officials were asked if pretreatment of chemical wastes was necessary prior to disposal. The responses were 16 percent positive, 58 percent negative, and 26 percent did not reply. Of those who replied positively, the treatment methods mentioned included dilution, neutralization, and assurance that contaminated containers are rendered totally useless.

Question 6. The respondents were asked if their disposal facilities have any special design features to accommodate waste from the chemical industry. Only 6 percent (four replies) answered affirmatively, while 75 percent said no, and 19 percent did not reply. Two cities indicated special pits and eventual cover for liquid chemical wastes and special cover of solid chemical wastes in sanitary landfills.

Question 7. This question asked for special problems encountered with waste from chemical industries. Problems were encountered by 30 percent, 31 percent indicated no problems, and 39 percent did not reply. Special problems mentioned included odors, fire and explosion hazards, and leaching into waterways. Fires are handled in one city by smothering if in solid materials, or by allowing burnout, if in liquids. One respondent indicated a special waste pit equipped with sprays for fire control. Several provide inspection prior to permitting chemical waste to be disposed at their facilities, and some indicated that special instructions are issued to haulers bringing in such wastes.

PART B Non-Municipal Refuse Disposal.

Question 1. The officials were asked if any problems occurred with private contract solid waste disposal facilities which handled waste from chemical industries. Responses were 11 percent yes (seven responses), 48 percent no, and 41 percent no reply. Of the yes responses, some indicated that problems with odors, fires, and leaching occurred with these operations. In one case deliverate fires, contrary to regulations, were mentioned, and another respondent indicated that the private operations in his jurisdiction did not give proper attention to the hazardous aspects of chemical waste disposal. Most of the negative or "no reply" respondents did mention a lack of knowledge of private operations or their problems.

Question 2. This question asked if chemical companies have difficulties disposing of their own chemical waste. Of those replying 9 percent (six replies) said yes, 33 percent said no, and the balance did not reply. Little elaboration was received from those who did reply positively. As in Question 1 above, many of the negative or "no reply" responses mentioned a lack of information on the internal waste disposal operations of chemical companies.

PART C Assessment of Chemical Plant Solid Waste.

Question 1. Officials were asked their opinion of the solid waste disposal practices of the chemical industries in their area. Although 36 percent did not reply, 28 percent rated them good, 28 percent rated them fair, and 8 percent rated them poor.

Question 2. The officials were also asked if restrictions on chemical industry waste disposal are under consideration. Of the replies 17 percent said yes, and 41 percent said no, with 42 percent not replying. Of those replying positively, none cited specific restrictions, but some indicated that water quality and sewer ordinances were presently being applied to regulate chemical waste disposal.

Question 3. The officials were asked to indicate which of several items best describe problems observed at chemical industry waste disposal sites. The replies were as follows: 34 percent indicated odors, 11 percent listed unsightly waste storage, 25 percent indicated potentially hazardous conditions, 8 percent cited standing water, 13 percent listed spillage from trucks hauling wastes, 8 percent cited uncontrolled and smoky burning, 13 percent indicated other problems. Of those mentioning other problems, several listed water pollution, and one cited "fallout" from incineration.

Additional comments were provided by 45 percent of the officials. Many of these were contacts suggested for additional information. The respondent from one large city indicated that there would be private disposal of objectionable liquid wastes by deep wells in early 1971. Another in the same area referred to a central multiplant disposal area under construction. Mention was also made by one respondent of consolidation of municipal landfill areas, with attendant improvements in control of types of waste disposed.

SECTION EIGHT: DISCUSSION OF FINDINGS, PROPOSED SOLUTIONS AND RECOMMENDATIONS

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SECTION EIGHT: DISCUSSION OF FINDINGS, PROPOSED SOLUTIONS AND RECOMMENDATIONS

Magnitude of the Solid Waste Disposal Problem

The magnitude of the problem of solid waste management in the industrial chemical industry is exemplified in the diverse types and large quantities of solid waste that must be handled, the expense of the required management systems, and the environmental problems encountered in waste treatment.

The characteristics of solid wastes generated by the industrial chemical industry are probably more varied than in any other industry. This is due to the many types of process wastes generated from the production of many thousands of different chemicals.

For those plants responding to the mail survey, the average quantity of non-process waste reported was 690 tons per year. The breakdown of average combustible and noncombustible non-process waste quantities was 562 tons per year and 207 tons per year, respectively.

Considering that a 15 cubic yard dump truck can carry approximately one ton of loose type #1 waste (rubbish) and four tons of noncombustible waste, a plant handling the average quantities of both combustibles and noncombustibles would require 12 truck loads a week hauled to disposal, or two per day in a six day week. The average storage period reported on the questionnaire was 10 days for combustible waste and 22 days for noncombustible waste. This storage period, applied to the average waste quantities generated, indicates a need by this average plant for 137 cubic yards of storage for non-process waste, or about 70 two-cubic yard containers. It is thus apparent that the average industrial chemical plant has a significant solid waste management problem with non-process waste alone.

Industrial chemical plant process waste generation was reported to be

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far greater than non-process waste generation. For plants indicating process waste generation the mean waste quantity for a single process waste type was 22,000 tons per year (Table 32). Assuming that this single process waste type is a sludge or filter residue at 75 pounds per cubic foot, and applying the average reported storage period of 33 days for all process wastes (Table 33), the mean storage capacity required would be 53,000 cubic feet. Considering only the mean reported sludge waste generation of 25,000 tons per year which has a far longer storage period of 115 days, the required storage capacity would be 214,000 cubic feet. For average filter residue generation (43,000 tons per year) with a storage period of 68 days, 213,000 cubic feet of storage capacity would be required.

The major disposal method for both sludge and filter residue wastes is landfill (68 percent of sludge and 76 percent of filter residue responses). At a maximum landfill depth of 10 feet and excluding waste shrinkage or cover material, land disposal area required for average sludge and filter residue generation would be approximately 2 acres and 3.3 acres per year, respectively. The industry's need for large storage and disposal facilities such as ponds and lagoons is apparent from these figures.

The average quantity of tar waste generated by those plants reporting tar waste generation was 596 tons per year. A tar burner of about 400 pounds per hour capacity, operated 6 days per week, 12 hours per day, would be needed for this quantity of waste. This is a small incinerator, but depending upon the combustion characteristics of the tar, it may require complicated air pollution control equipment.

Thus, the plant disposal system for process wastes must be large enough to handle the substantial waste volumes and capable of handling different types of wastes.

Plants responding to the process waste questions of the mail survey averaged 1.5 process waste types per plant, with all but small plants averaging over two. The average industrial chemical plant responding to the mail questionnaire generated approximately 33,000 tons per year of process waste of more than one major waste type. Applying the generally accepted generation rate of 5 pounds per person per day (0.8 tons per year) of municipal refuse in the United States, our average plant generates the waste tonnage equivalent of a city of 37,500 people. This result is based on the average of 690 tons per year of non-process and 33,000 tons per year of process wastes, for a total of 33,690 tons per year for the average plant.

While the survey results cannot be projected on a total national basis, it is apparent that solid waste from the industrial chemical industry can be as serious a problem in terms of quantities as that generated by individuals.

The cost to the industry of solid waste management was found to be substantial and of great concern to plant management. The average cost for non-process waste disposal for plants responding to the mail survey, including collection and transportation, was $32.80 per ton for combustible and $23.80 per ton for noncombustible solid waste. The corresponding weighted* average cost was $14.98 per ton for combustibles and $12.35 per ton for noncombustibles, while the overall weighted average cost was $14.11 per ton of non-process waste. This result reflects the decrease of disposal costs as solid waste quantities increase. These figures may be compared to typical costs of $20-$30 per ton for disposal and collection of municipal solid waste. The weighted average cost and the annual average generation of non-process waste results in a total yearly cost of approximately $9,700 for non-process waste management.

The cost of solid waste management from process waste fluctuates widely from plant to plant, due mainly to the variability of waste types, the extreme range of annual process waste quantities (from one ton to over a million), and the wide differences in disposal methods utilized (from complex incinerators to simply dumping on the ground). This wide variability is illustrated by comparison of the mean per ton cost with the weighted average for all process wastes and all plants. The overall mean shown on Table 36 was $44.67 per ton, computed as the average of each responding plant's dollar per ton cost. The weighted mean was $4.10 per ton from the mail survey and $2.73 per ton from the plant visits. The weighted mean cost from the mail survey can be applied to the reported average annual plant process waste generation rate of 33,000 tons per year, to provide an average estimate of $135,000 per year for solid waste management of process wastes. When this is added to the average cost of non-process waste management, a total annual estimate of approximately $145,000 is obtained for management of solid waste by the typical industrial chemical plant responding to the mail questionnaire.

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*The average obtained by summing the product of per ton cost and tonnage for each reply, divided by total tonnage reported.

The relatively low weighted figure for process waste disposal costs is significantly influenced by the low cost of disposal for extremely large quantities of sludge and filter residue which are disposed of in lagoons or diked areas. This type of disposal is generally coupled with pipeline transport and is usually inexpensive.

Industrial chemical plants reported that they expect future solid waste generation to increase significantly. Sludges and filter residues, the two predominant process wastes, were expected to increase 50 percent or more in the five years between 1970 and 1975, as shown in Table 39. The decrease in flyash generation is probably due to the conversion of many plants from the burning of coal to low ash content fuels such as oil and gas. Off-quality product waste also showed a projected decrease which may indicate the beginning of a trend within the industry to reduce this type of waste through increased production efficiency. All responses for increased solid waste generation were projected for existing solid waste streams. Plants did not report future generation from expected new sources brought about by new processes or changes in plant operations. These wastes would be projected increases to the existing quantities. Although the survey indicates a rather definite trend for increasing quantities of process waste, few respondents projected waste management costs five years from now, except to the extent that they would be influenced by increasing quantities.

Environmental problems are potentially associated with disposal and industrial chemical plant solid waste in all environmental mediums: air, water, and land. The degree to which a waste can contribute to environmental pollution is highly variable depending on waste characteristics and disposal methods employed, yet all wastes can be a potential problem. Significant in this respect is that almost as many process wastes were considered by responding plants to be toxic as were considered to be inert (40 percent versus 60 percent).

Air pollution may occur when odors or noxious gases are emitted from decomposition or incineration of the waste, requiring that special disposal procedures be followed. Inert wastes may also contribute to air pollution if they cause dusting when exposed to the elements. There is a current trend toward stricter air pollution regulations which may prohibit or require modification of certain plant solid waste disposal practices. For example, open burning has been prohibited in many areas, and current emphasis appears to be on more efficient air pollution control equipment for incinerators. More rigid control of other air pollution sources at some plants may also result in additional solid wastes (such as increased amounts of flyash withdrawn from boiler flue gases).

Water pollution is associated with solid waste disposal under the following conditions: (1) When noxious liquid chemicals contained within the solid waste leach into water supplies. This may occur in wet sludges and filter residues or tars which are dumped on the ground or buried; (2) When soluble portions of the solid waste are dissolved in ground or surface water; (3) When the liquid portion of a slurry is passed into receiving waters; and (4) When scrubbing liquids used to remove noxious gases and particulates from stacks of solid waste incinerators or powerhouse boilers are sent to receiving waters.

Regulations dealing with disposal of waste liquids are becoming increasingly more restrictive. Regulations dealing with groundwater contamination are similar to those of surface waters, but to date have not been enforced as vigorously. It is difficult to trace the source of groundwater contamination, and the effects of the contamination may not be apparent for some time after the disposal of the solid waste. Greater emphasis on eliminating sources of groundwater pollution can be expected, probably resulting in increased restrictions on the practices of burying, ponding, or otherwise exposing wastes to the land.

The concentration of suspended solids in waste streams is limited by water pollution regulations. Any further reduction of permissible solids concentration will result in additional solids removal and subsequent disposal needs. In addition, as treatment requirements increase, more plants will install biological treatment systems which will result in additional sludge wastes.

Land pollution may occur if the solid waste contaminates the soil, rendering it incapable of supporting plant growth or wildlife, or if it causes hazards which preclude development of industry or dwellings. Rendering a relatively small piece of land sterile was unimportant in the past when there was so much land available, but as population grows, there will be greater emphasis on preserving those natural areas which previously might have been prime sites for disposal operations. These include marshes, lowlands, river banks, etc. As land costs rise, the utilization of land at its highest level will be increasingly important to both industry and the public, and disposal operations which remove land areas from consideration for future development will be considered wasteful and expensive. At the present time, there is very little legislation regarding land pollution, but it is expected that restriction of land disposal to protect the soil and to preserve land areas will eventually be instituted, and this will add still another factor to be considered in the planning of disposal systems for chemical solid wastes, and indeed for all solid wastes.

One responding plant reported a problem which serves as an excellent example of land use difficulties brought about by inadequate solid waste management practices. During the early days of the plant operation, chemical wastes were buried in barrels, but accurate records of the waste characteristics and disposal sites were not kept. Now as the plant expands and these areas are built on, extreme precautions must be taken to avoid accidents during excavation, since the nature of the waste is unknown and it may be hazardous.

Waste disposal methods and practices are aggravated not only by increasing environmental and ecological restrictions, but also by the changing nature of chemical wastes themselves. The trend in chemical production today is toward more complex and highly reactive materials, and the waste from these new processes will be equally complex and will require more sophisticated disposal methods. The individual plant is therefore challenged to examine its own wastes from each process and to develop the best solid waste management plan. In contrast, other industries such as steel, paper, brewing, and meat processing ordinarily have waste problems which are common within the industry, and if a satisfactory solution is developed by one plant, the disposal method often is adopted by

TABLE 40
COMPARISON OF SOLID WASTE MANAGEMENT CHARACTERISTICS BY REGION

Characteristic		Size of plant (based on employment)	Region	Nature of manufacture
General	Size of plant site	increasing plant site size with increasing size of plant	regions I & II and VIII & IX have plant sites smaller than the mean	SIC 2812 and 2813 plants occupy smaller than average sites
	Nature of area surrounding plant		regions I & II have higher percent of plants in urban areas	
	Use of public site	small and extra large plants report greater use	regions I & II and VIII & IX report greater use, and V & VI and VII lesser use	SIC 2812 plants use them most, and SIC 2813 plants use them least
Non-process waste	Disposal cost	decreasing cost with increasing plant size except for extra large plants	regions VIII & IX and III & IV have higher costs	
	Disposal method	large and extra large plants have higher than average use of incinerators	regions VIII & IX have higher use of landfill	
	Waste quantity	increasing quantities with increasing plant size	regions I & II have higher generation, and regions VIII & IX have lower generation than the mean	SIC 2812 and 2813 generate lower than average quantities
Process waste	Storage period	decreasing storage period with increasing plant size	regions VII and VIII & IX utilize larger than average storage period, and regions V & VI the shortest period	SIC 2819 exhibits longer than average storage period
	Storage type	progressively greater use of containers with increasing plant size	regions VII and VIII & IX have the lowest use of containers and highest percentage of no storage (pipelines)	SIC 2815 has a greater use of containers and lower than average use of other storage methods
	Transport method	small and medium plants exhibit the greatest use of pipeline transport	regions VII and VIII & IX possess higher than average use of pipelines	SIC 2815 has the highest use of truck and lowest use of pipeline, and SIC 2813 has the lowest use of truck and highest use of pipeline

TABLE 40 (cont.)

Characteristic		Size of plant (based on employment)	Region	Nature of manufacture
Process waste (cont.)	Disposal agency	extra large plants exhibit lowest govern-use, large plants use private contract most, medium plants exhibit highest government use	regions V & VI lowest use of captive and highest use of private contract	SIC 2812 possesses high use of government disposal sites
	Disposal cost	medium plants exhibit the highest cost and large plants lowest cost	regions I & II and III & IV report the highest costs	SIC 2818 reports by far the highest cost
	Disposal method	extra large plants exhibit greatest use of incineration and large plants the greatest use of lagoons	regions III & IV report lowest use of land disposal and highest use of the incineration	SIC 2818 and 2815 report greatest use of incineration and lowest use of lagoons
	Waste quantity	medium plants report the highest quantity and small plants the lowest quantity	region VII report the highest generation and regions I & II the lowest generation	SIC 2819 reports the highest generation and SIC 2813 the lowest generation

the entire industry.

In general, the industrial chemical industry is well-equipped to solve its solid waste disposal problems. Chemical markets remain relatively stable over long periods, thereby providing a solid economic background. Investments in pollution control can be expected to be repaid in the lifetime of most chemical processes. As in other industries, the most economical point for formulation of waste management policies is ast the process design stage. Since pollution control is eventually reflected in higher prices, it is only good competitive business to minimize such increases by controlling pollution at this stage. The chemical industry has shown a willingness to take this position in air and water pollution control, and as indicated by this survey, is beginning to turn similar attention to solid waste disposal.

Solid Waste Management System Characteristics

The characteristics of a solid waste management system may vary with the size of the plant, the location of the plant, and its predominant manufacturing activity, as shown in Table 40. Two centers of industrial chemical manufacture in terms of number of plants and value added by manufacture are the states of New Jersey (region I) and Texas (region VII) (see Section Two). The chemical plants in these states handle higher average quantities of non-process solid wastes than plants located in the other states. The survey also showed that non-process waste generation is generally a function of plant size, i.e., the larger the plant, the more waste generated. Thus, the rate at which industrial chemical non-process solid waste is generated in an area appears to be related to industry concentration in the area.

Although plants in region VII responding to the mail survey also indicated the highest quantities of each process waste type, the generation of process wastes is not necessasrily related to industry concentration in a geographic area. Regions I and II, which contain the greatest number of plants, reported the second highest average sludge waste quantities, while plants in regions VIII and IX reported the second highest average filter residue waste quantities. Plants in regions V and VI reported the second highest quantities of tars. Process waste generation is also not related to plant size. For example, medium-size plants reported the highest overall process waste quantity, and the highest sludge and filter residue waste quantities. The quantity of process waste generated in a geographic area is probably more related to the types of industrial chemicals produced and the processes used by the individual plants, than it is to industry concentration.

The availability of adequate land area on the plant site was found to be a major factor in whether a plant operates onsite disposal facilities, or must use its own offsite facilities, those of private contractors, or those of the municipality in which it is located. If potential air, land, or water pollution from onsite disposal operations is discounted, solid wastes from industrial chemical operations have their greatest impact on the community when public facilities are used. The mail questionnaire results indicated that 32 percent of the responding chemical plants are located in urban areas. These plant sites would be expected to be smaller due to the high land costs and general lack of undeveloped land, and they can be expected to make greater use of public solid waste facilities. Forty-one percent replied that their sites were located in rural areas where more land is available, and these chemical plants could be expected to use public disposal sites to a lesser degree. The average plant site size reported by the survey was 199 acres, of which only 44 percent was devoted to production facilities. These figures are strongly influenced by the large percentage of responses from plants located in rural areas.

In regions VIII and IX and I and II, much smaller plant sites were reported, with greater percentages devoted to production facilities. These regions contain some of the most densely populated urban areas in the country, and a high percentage of plants did indicate their location to be in urban areas (44 percent for regions I and II and 33 percent for regions VIII and IX). These regions also reported the highest percentage of plants using public solid waste disposal sites, 55 percent and 56 percent respectively, whereas the overall average of plants using public solid waste disposal sites was 42 percent.

Most of the plants reporting use of public facilities used them for non-process waste. Of the two-thirds of non-process waste disposed offsite, 52 percent was disposed at public facilities, whereas of the 61 percent of process waste disposed offsite, 30 percent was disposed of at public facilities. A large portion of the process waste disposed at public facilities was flyash and "other process waste", relatively inert constituents.

Variations in management systems for non-process and process waste characteristics are also shown on Table 40. Regions VIII and IX and III and IV were found to have the highest unit disposal costs for non-process waste, and costs increased with plant size (except for extra large plants which had lower costs than large plants). Both large plants and extra large plants exhibit a higher than average use of incineration for non-process waste, and extra large plants apparently are able to reduce their unit disposal cost by employing large scale disposal equipment. Plants in SIC 2812 and 2813 reported a lower overall average non-process waste quantity than the other SIC categories, probably due to the large number of small plants comprising the categories.

For process wastes, extra large plants were found to make the greatest use of containerized storage, have the shortest storage period, the greatest use of incineration, and used government disposal facilities least. Medium size plants, on the other hand, reported the greatest use of government facilities, the highest unit disposal cost, and the largest mean process waste quantity of other size plants. These results point out that plant size categorization based on numbers of employees is not indicative of process waste generation or the impact in terms of solid waste that a plant will have on the surrounding community.

Regions III and IV reported the lowest use of land disposal and highest use of incineration, as well as a higher than average unit disposal cost for process waste. Regions I and II also reported higher than average unit disposal costs, but exhibited the lowest mean generation of process waste. Regions VII, VIII and IX reported the least use of containers and the greatest use of pipeline transport. The process waste generated in these regions was held in storage for longer than the average period. Regions V and VI reported the lowest use of captive diposal sites and the highest use of private contractors, as well as a shorter than average storage period.

The variations in characteristics of management techniques among SIC categories reflect the nature of the process waste generated. Plants in SIC 2819 produce inorganic chemicals, and the solid wastes generated are generally also inorganic materials. A few processes within this category generate unusually high quantities of solid waste, and as a result this group exhibited the highest average generation of process waste. Inorganic wastes are most amenable to long storage periods and disposal in lagoons, and are quite difficult to incinerate.

Solid wastes from organic chemical production, SIC 2818 and 2815, are generally organic material. Organic wastes will tend to decompose if stored too long, and are amenable to incineration. Survey results showed that SIC

2815 wastes exhibited the greatest use of containerized storage and truck transport, and along with SIC 2818, a greater than average use of incineration. The highest unit cost for disposal of process waste was exhibited by SIC 2818. The lowest generation of process waste was exhibited by SIC 2813, industrial gases, the majority of which was waste lime from production of acetylene, normally transported to disposal by pipeline.

The greatest impact on public disoposal facilities of solid wastes from industrial chemical plants appears to be due to chemically contaminated materials that are mixed with non-process waste and the small quantities of process waste disposed of at these facilities. Sixty-six percent of the officials responding to the municipal questionnaire indicated that chemical industries used municipal disposal facilities, at least somewhat. Of these, 30 percent indicated that they encountered problems, such as odors, fire and explosion hazards, and leaching. Sixteen percent also indicated that pretreatment of this waste was necessasry, including dilution, neutralization, and decontamination of containers.

When asked to describe the problems observed at disposal sites treating industrial chemical plant wastes, the officials indicated that odors and potentially hazardous conditions were the predominant problems. In rating these disposal sites, 28 percent of the officials rated them "good" and 8 percent rated them "poor". Their rating of private contract disposal sites was somewhast similar, with 11 percent indicating that problems did occur at these facilities and 48 percent indicating no problems.

Solutions to the Solid Waste Management Problems

The most direct method of controlling the quantity of solid waste produced by industrial chemical plants is the reduction of solid waste generation at the source; i.e., the basic process operations. The ideal point for application of this approach is during the process design stage. When a waste is expected to be produced, the process designer, who knows best the nature of the solid waste, should be responsible for specifying the disposal system.

Many individuals within the industry involved in solid waste disposal advocate this approach, and argue that the time is rapidly approaching when waste generation will become one of the most important factors in determining the efficiency and worth of a process. Under these circumstances, there would be far greater concern over the quantity and types of waste generated than today when, for most chemical processes, the total quantity of waste material emitted to air, water, and land is not well-known.

Once a solid waste is generated, there are two alternatives to its disposition-disposal or salvage. The great majority of waste inventoried in this study was discarded. Solutions to the problems of the disposal alternative involve development of novel and improved ultimate disposal methods and more efficient management systems.

One of the most immediate, yet usually simple improvements that can be made in plant storage, collection, and transportation systems for solid wastes is the elimination of obvious nuisances such as odors, spillage, and unsightliness. A major objection to chemical plant disposal operations cited by municipal facilities was the spillage of solid wastes. An example of a straightforward correction of this type of problem was given by a company which hauled flyash from their boilers to a landfill disposal area. They did so in trucks equipped with metal covers which were clamped over the loads. This eliminated any possible blowing or spillage of the flyash and provided a neater appearance to the operation.

New disposal methods must emphasize abatement of environmental pollution, reduction of the waste to the smallest possible volume, and recovery of valuable constituents within the waste. General examples of effective disposal operations were observed during the plant visits conducted for the survey. An excellent tar burner system was observed at one large plant, which included storage tanks for tars of different characteristics to allow for blending to provide a proper feed to the burner. Temperatures in this unit are maintained in the range of 2800-3000 F, and combustion gases are quenched in a spray chamber, followed by a high-pressure drop venturi scrubber and a cooler mist-eliminator. All waste water from the burner is piped to the plant waste water treatment system, and the stack gases are periodically sampled to assure that air pollution regulations are not violated.

Another tar burner was observed which was equipped with a waste heat boiler. Although maintenance costs for this incinerator were high due to the high furnace temperatures, a significant reduction in operating costs was achieved by virtue of steam generation. The tar burner operating cost was about $10 per ton of tar burned, while the waste heat boiler produced about $7.50 per ton of tar in steam credits. Gas streams from other parts of the plant were also piped to the burner for odor control.

In some of the more progressive plants, a solid waste sample is first sent to the laboratory where its combustion products and characteristics are determined. In this manner, potential air pollution problems or damage to the incinerator can be assessed before full scale problems arise.

An example of an effective landfill disposal operation, which is used for process wastes only and does not accept liquids, or oils in either bulk or barrel form, was also observed. A crane is operated at the site for mixing soil with all solid wastes to assist decomposition. A bulldozer is also used to move waste materials and to provide cover and compaction. The landfill was sealed prior to the start of operations and a dike of hard packed clay was constructed to keep liquids from leaching out of the fill. A drain is provided within the dike to collect any liquids accumulating within the landfill, so that they can be piped to the plant waste water treatment system. All surface water is drained away from and around the landfill to assure that there is no leaching into groundwater, and test borings have been drilled around the site to monitor the groundwater quality. As in this case, proper monitoring of possible environmental effects of disposal methods is essential to close the loop on an effective system. Not enough is know today about the effects of disposing of chemical process wastes to predict accurately all of the potential environmental effects. Through monitoring, adverse effects can be discovered early and remedial action can be promptly taken.

Salvage of solid waste, including recyling, recovery, and utilization is preferable to disposal. A detailed discussion of solid waste recycling recovery and utilization for the industrial chemical industry has been presented in Section Five. In most cases, salvage possibilities and procedures must be developed for each individual solid waste due to the variable characteristics of process wastes of the industry. Combustion with heat recovery, however, can be applied to many solid wastes. This process can be accomplished either in incinerators such as the tar burners previously mentioned or in the main plant boilers as discussed in Section Five.

The trend toward incineration of process wastes should be accompanied by a more frequent use of heat recovery systems. Some environmentalists contend that destruction of potentially valuable resources by incineration is poorly compensated by the heat energy derived therefrom. Yet, an accepted environmental policy allows the conversion of heat and power generating installations from the burning of coal and oil to burning natural gas, which is one of the most valuable sources of raw chemicals. In view of this, the production of heat energy from waste chemicals which would otherwise be discarded appears justifiable.

Other salvage possibilities can be determined only by thorough analysis of the particular waste to assess its potential. Some examples of existing solid waste salvage operations in the chemical industry are given in Section Five. The U.S. Bureau of Mines conducts research programs aimed at developing technically feasible and economical methods for treating solid wastes and secondary raw materials to recover and recycle valuable metals and minerals. One such project seeks to produce elemental sulfur from gypsum wastes such as those generated by phosphoric acid production. The U.S. Environmental Protection Agency too conducts extensive research in this area.

As disposal requirements become more extensive, many plants have begun to look to outside companies for help, since they believe that extensive solid waste disposal systems are not always compatible with industrial chemical manufacture. These systems are generally a nonprofit function within the chemical plant which many believe could best be handled at a profit by companies specializing in this field.

In the past, many private contractors operated disposal facilities, which were inadequate for chemical process wastes. Chemical plants have recently become concerned with the disposal methods used by these contractors, since the courts have found that damage caused by improper disposal can be partly attributable to the originator of the wastes.

One situation was observed during the plant visit portion of the survey where a number of companies in a particular area joined together and prevailed upon a local contractor to operate a disposal site for certain process wastes. The plants helped detail the correct disposal procedures, but the facility was owned and operated by the contractor. Disposal was by ponds cut into dense clay, and the contractor had little trouble keeping the site neat and clean with his substantial array of available earth moving equipment. Monitoring of nearby streams indicated no detectable leaching.

Unfortunately, there exist very few companies today who are equipped to handle a variety of industrial process wastes. Some chemical scrap companies do exist, but they are quite selective in the waste chemicals they handle.

Most industrial representatives contacted during this study were very receptive to the concept of effective contract disposal. If the few companies now entering this field can succeed, undoubtedly they will be joined by many others. In the future, this approach may then become a major solution to the solid waste management problems of the industrial chemical industry.

A private disposal company is currently being formed in one section of the country to handle industrial wastes, primarily from the refining, petrochemical, and chemical industries. This company states that while an "in-plant" disposal facility gives the plant complete control of disposal and allows design of facilities for a specific mixture of wastes, it is far more expensive and the disadvantages are many, when compared to centralized waste treatment. This company lists the advantages of central industrial waste disposal facilities as shown in Table 41.

Recommendations for Further Research and Development

The need for further research and development (R & D) applied to the management of chemical process wastes was highlighted by a number of problem areas uncovered by this study. These problem areas have just been discussed.

The R & D efforts should be concentrated in two areas: (1) the determination of the environmental effects of current solid waste disposal practices of the

TABLE 41

ADVANTAGES OF CENTRALIZED INDUSTRIAL WASTE DISPOSAL FACILITIES*

1. Economy of scale
2. Lower total cost
3. Zero capital investment by operating companies
4. Facility is not occupying operating companies' property
5. No reports, sampling, inspections
6. No meteorological forecasting
7. Hazard- and nuisance-free
8. Wastes can be blended beneficially
9. Technical control
10. Full-time specialists
11. Continuous operation
12. Assurance of future means of disposal at lower cost regardless of changes in law
13. Expansion and additions at low unit cost
14. Management free
15. Favorable community image
16. No project or startup problems

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*From Reference #74.

chemical industry; and (2) the development of improved waste management systems and procedures, including investigations of techniques to render chemical solid wastes innocuous.

From the industry's standpoint, the second area would be most valuable, and to some extent its beginnings are already available from within the industry. During the study, a number of exceptionally well-designed and controlled disposal operations were encountered, where the potential for environmental pollution was at a minimum. In contrast, there were also some extremely poor facilities with all potentials for pollution maximized. This current industry experience, both good and bad, could be translated into guidelines for the appropriate disposal of chemical process wastes.

These guidelines would detail the best procedures for disposal of sludges, filter residues, tars, off-quality product, etc., by means of the common disposal methods: landfill, incineration, ponding, lagooning, and ocean disposal.

In most cases encountered in the study where process wastes were inadequately disposed of, the greatest contributing factors were a lack of knowledge of correct facility design and disposal procedures, and a lack of understanding of the necessity for these requirements. Guidelines for design and operation would provide a meaningful start for the alleviation of these current situations and to encourage planning and development of future improvements.

In addition to the proposed guidelines, other areas requiring research attention are:

(1) The environmental effects of land disposal of chemical process wastes. This area should be subjected to careful study, including the mechanisms of process waste decomposition in the soil and the effects on soil types, including the biodegradability of the waste.

(2) The development of techniques for recyling, recovery, and utilization of chemical process solid wastes. This area should be subjected to studies which concentrate on analysis of new processes and the economics of waste salvage, including the possibilities of economic incentives.

(3) The development of new solid waste disposal techniques which accent reduced pollution and economic operation. This area should be subjected to studies which incorporate the total esystems aspects of the disposal problem. The integration of the disposal method into the total plant operation should be emphasized, as should the integration of this method into the chemical process at the time of process design.

(4) The effect on solid waste generation of more stringent air and water pollution regulations. The extent to which greater quantities of solid wastes are produced by virtue of more effective controls in removing solids from chemical plant gaseous and liquid discharges should be studied.

(5) The ecological effects of ocean disposal of chemical process wastes. The quantities and types of wastes disposed of in this manner should be determined, and their transport, decomposition, and effect on the ocean environment should be studied.

(6) The development of alternatives to landfill disposal. It is probable that in the not too distant future, land disposal of chemical wastes will be prohibited. At this time alternative disposal methods should be available for chemical wastes now disposed of in this manner.

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APPENDIX

TABLE 42

INDUSTRIAL CHEMICAL MANUFACTURE SIC #281 BY STATE AND REGION (U.S. PUBLIC HEALTH SERVICE REGIONS)*

		1967 Value added by manufacture		1967 Number of manufacturing plants (20 employees or more)	
		Millions of dollars	Percent of U.S. total	Number	Percent of U.S. total
I.	NEW ENGLAND	66	0.8	25	2.5
	Connecticut	N.R.	---	N.R.	---
	Maine	N.R.	---	N.R.	---
	Massachusetts	46	0.6	17	1.7
	New Hampshire	N.R.	---	N.R.	---
	Rhode Island	19	0.2	8	0.8
	Vermont	N.R.	N.R.	N.R.	---
II.	MIDDLE ATLANTIC	1334	17.2	240	24.3
	Delaware	N.R.	N.R.	N.R.	---
	New Jersey	787	10.2	128	12.9
	New York	327	4.2	52	5.3
	Pennsylvania	220	2.8	60	6.1
III.	EAST SOUTH CENTRAL	1000	12.9	90	9.1
	Kentucky	179	2.3	18	1.8
	Maryland	88	1.1	21	2.1
	North Carolina	46	0.6	15	1.5
	Puerto Rico	N.R.	---	N.R.	---
	Virginia	104	1.3	14	1.4
	West Virginia	583	7.5	22	2.2
IV.	SOUTH ATLANTIC	830	10.7	98	9.9
	Alabama	111	1.4	20	2.0
	Florida	82	1.1	21	2.1
	Georgia	68	0.9	20	2.0
	Mississippi	46	0.6	5	.5
	South Carolina	N.R.	---	N.R.	---
	Tennessee	522	6.7	32	3.2

TABLE 42 continued

		Millions of dollars	Percent of U.S. total	Number	Percent of U.S. total
V.	EAST NORTH CENTRAL	1195	15.4	184	18.6
	Illinois	284	3.7	53	5.3
	Indiana	130	1.7	23	2.3
	Michigan	355	4.6	30	3.0
	Ohio	414	5.3	70	7.1
	Wisconsin	13	0.2	8	.8
VI.	WEST NORTH CENTRAL	353	4.6	50	5.1
	Iowa	49	0.6	9	N.R.
	Kansas	99	1.3	14	N.R.
	Minnesota	N.R.	---	N.R.	---
	Missouri	162	2.1	19	1.9
	Nebraska	43	0.6	8	0.4
	North Dakota	N.R.	---	N.R.	N.R.
	South Dakota	N.R.	---	N.R.	---
VII.	WEST SOUTH CENTRAL	2037	26.3	142	14.4
	Arkansas	75	1.0	9	.9
	Louisiana	507	6.5	43	4.3
	New Mexico	N.R.	---	N.R.	---
	Oklahoma	7	0.1	5	.5
	Texas	1447	18.7	85	8.6
VIII.	MOUNTAIN	9	0.1	9	1.0
	Colorado	9	0.1	6	.6
	Idaho	N.R.	---	N.R.	---
	Montana	N.R.	---	N.R.	---
	Utah	N.R.	---	3	.3
	Wyoming	N.R.	---	N.R.	---
IX.	PACIFIC	467	6.0	104	10.5
	Alaska	N.R.	---	N.R.	---
	Arizona	6	0.1	3	.3
	California	303	3.9	81	8.2
	Hawaii	N.R.	---	N.R.	---
	Nevada	N.R.	---	N.R.	---
	Oregon	21	0.3	6	.6
	Washington	137	1.8	14	1.4
TOTALS ALL STATES		7737*	94**	989*	95.4**

N.R. - Not reported

*Totals including those not reported for individual states.

**Percentages based on actual total; therefore do not equal 100 percent

*From Reference #66.